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Directions In Concrete Research

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Abstract:

The last decade has seen major changes in practice, in the use of new materials and in methods of concrete construction. In recognition of this and of major changes in the materials supply industry, MTO determined a need to develop a long range research programme. This report reviews current MTO practice and that of other highway agencies. It reviews up-to-date materials practice and research now being undertaken in other countries.

Five policy options have been developed for consideration by the Ministry: a) Improve and extend technology transfer within the Ministry and between the Ministry and Industry; b) Complete certain materials research and development programmes already started; c) Establish and if necessary improve the service life of concrete; d) Develop new generation materials for highway applications; e) Improve the aesthetics of structural concrete.

The cost-benefit and other implications of the projects, which must be completed before the proposed policies can be implemented, have been described. Projects have been assigned priorities both with regard to relative importance and a rational chronological order.

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Key Words: concrete, materials, aesthetic, QA technique, reinforcement, shotcrete, grouting, bridge deck, pavement, industry, research, technology transfer, changes.

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EXECUTIVE SUMMARY

The last decade has seen major changes in practice, in the introduction and use of new materials and in methods of concrete construction. In recognition of this and of major changes in the materials supply industry, the Ontario Ministry of Transportation has determined a need to develop a long range research programme.

This report reviews current MTO practice and that of other highway agencies. It reviews up-to-date materials practice and research being undertaken now in other countries. Researchers and practitioners within and outside the highway field were consulted. Up-to-date literature was reviewed where appropriate, as were past MTO research and development reports.

In considering the challenges faced by the Ministry the potential availability of the results of research underway at other agencies was taken into account.

Five policy options have been developed for consideration by the Ministry:

A. Improve and extend technology transfer within the Ministry and between the Ministry and Industry.

B. Complete certain materials research and development programmes already started.

C. Establish and if necessary improve the service life of cover concrete.

D. Develop new generation materials for provincial highway applications.

E. Improve the aesthetics of structural concrete.

The cost-benefit and other implications of the projects which are needed to implement the proposed policies have been described. Projects have been assigned priorities both with regard to relative importance and a rational chronological order.

Recommendations to improve technology transfer emphasize monitoring research worldwide, increases in networking with industry and improvements in the knowledge and experience of Quality Assurance staff. The improvements in concrete quality envisaged will require industry co-operation. Industry will have to see an ongoing volume of work and will need to know early of planned new developments which require new technology and equipment. The Ministry can benefit by input to R&D by Academia and Industry.

Ministry projects in hand to improve and control concrete quality should be completed. These include control of alkali-aggregate reactions, improvements in shotcrete and grouting materials and processes, and assurance of specified cover to reinforcement.

The quality of cover concrete is an essential factor in achieving durable concrete. Ministry specifications are typical of good practice but the actual quality achieved in the field is unknown. This critical area needs extensive investigation to determine if what is being produced now is adequate or whether new generation materials are needed.

There are many ways in which new generation materials can benefit Ontario. The development of high-early strength but durable, volume stable concretes are needed for pavement and structure repairs. High performance concretes incorporating new materials can provide better bridge deck and highway overlays and high strength pavement concretes of great durability. New QA techniques can improve quality for a given expenditure. Recycling of old pavements and the use of waste materials can help meet environmental and energy saving objectives.

To improve the visual environment higher aesthetic standards for structural concrete are suggested. Suggestions for financial participation and co-operation by industry are made to facilitate research.

ACKNOWLEDGEMENTS

The study was guided by a Steering Committee consisting of David Manning, Hannah Schell and Alan Ip.

Day-to-day management of the project was provided by Alan Ip, Research Engineer, Research and Development Branch, whose cheerful, helpful and efficient direction is gratefully acknowledged.

Input to this study was provided by those listed in Appendix II. Their help was of great value to the writer.

The views expressed in this report are those of the writer, and no attempt was made by MTO staff to influence these.

1/Introduction

1.1/Background

The Ontario Ministry of Transportation has recognized the necessity to review the problems that affect the quality of its concrete work. It has stated the problem in the Needs Statement for this report as follows.

"The number of factors which affect the quality of concrete in Ministry work have increased in recent years. New materials have been introduced to the marketplace, often with insufficient knowledge of long term performance or compatibility with other ingredients of the concrete mixture. At the same time that it is necessary to avoid materials which may compromise concrete quality, it is essential that the Ministry take advantage of developments in materials, equipment, construction and quality assurance techniques that will lead to greater economy, speed of construction, and quality of concrete.

Changes in materials, equipment and construction practices are occurring at the same time that institutional changes are occurring. Within the Ministry, examples are: the introduction of end-result specifications, retirement of senior staff, and a diminished program of concrete-related research during the past few years. Within the industry, examples are that vertical integration has affected competition, and technical support from industry-supported organizations has diminished."

1.2/Survey Objectives

The aim of this study, as stated in the Needs Statement, is as follows:

"The overall objective is to prepare a long range (5+ years) research plan which will identify research projects designed to result in optimum concrete practices by the Ministry through an appropriate balance of quality and economy. The study comprised the following tasks:

Task 1: Examine the Ministry's and construction industry's practices pertaining to concrete materials (including materials selection, mix proportioning, specifications, quality control and assurance practices, and construction techniques), the literature, and activities in comparable organizations in Canada and elsewhere.

Task 2: Formulate strategic directions for concrete research and examine the cost/benefit and risk implications of each option.

Task 3: Prepare a research plan detailing the projects which would have to be undertaken in support of the directions deemed most appropriate.

Task 4: Prepare a final report on Tasks 1, 2 and 3."

The report is not to include consideration of research projects in the field of corrosion of reinforcement.

2/Study Methods

2.1/Background Information

Ministry concrete practices are clear from a study of MTO standard specifications and visits to highway construction sites. Also copies were obtained of all relevant results of previous Ministry research projects both internal and external. These provided insight into which problems had been tackled and what gaps had still to be filled in specific areas.

Discussions were held with MTO staff, transportation agency staff in other jurisdictions in North America and abroad, and with other practitioners with interest or experience relevant to this project, as it is the author's experience that person-to-person contact is the best way of soliciting significant assistance.

A list of all those contacted specifically with regard to this project is given in Appendix 2. In addition informal discussions were held with many delegates at a number of technical meetings. These meetings are listed in Appendix 3.

2.2/Literature Search

A formal literature search was not conducted. Exposure recently to representatives of various international groups involved in research yielded many documents not yet in the literature, and those already published which were germane to this project were identified. In addition recent literature searches on other research projects had already identified documents of interest for this project. The documents consulted are listed in the bibliography.

2.3/Libraries

The author's extensive library was used for some source material. As stated above, copies of all relevant Ministry reports were also obtained.

3/MTO Construction Practice

3.1/Design and Constructability

Designs require conventional concretes of 30 and 35 MPa. Insofar as high strength concrete is concerned, this has not been used since the Willows Bridge[1]. No design advantage is seen in the use of high strength concrete in typical bridge designs.

Observation during the construction of piers, columns and decks of major bridges and interchanges would suggest that constructability was not foremost in the designers' minds.

3.2/Specifications

3.2.1/Introduction

Concrete work is governed by Ontario Provincial Standard Specifications and Special Provisions.

Of relevance to this project are the following sections:

Division 3 - Pavement (Flexible and Rigid)
Division 9 - Structural
Division 10 - Aggregates
Division 13 - Cement and Concrete
Division 14 - Metal
Designated Sources for Materials
Special Provisions

3.2.2/Division 3

OPSS 315 for Cement Treated Granular Base and Sub-Base provides for a roller compacted concrete or slip-formed concrete similar to the cement bound granular base (CBGB) widely used in the UK motorway construction. A 5% cement content is implied using normal portland cement and an aggregate complying with granular A or B requirements, and this is the cement content commonly used. The mix design is provided to the contractor by the Ministry. The only performance criterion for the finished material is a requirement for a minimum dry density after compaction. Despite a low cement content this is a potentially high quality material. This base concrete is not air-entrained.

It is noted that continuous mixers are allowed subject to achieving the proportioning accuracy required by the specification. The use of continuous mixers could introduce lower quality control than batch mixers. There is no Section 8 on Quality Control in this specification.

OPSS 350 for Concrete Pavement, Concrete Base and Lean Concrete Base provides for three grades of structural pavement with a surface finish typical of exposed pavement. While mix designs are the responsibility of the contractor, all the essential mix parameters for lean concrete base are specified. The only adjustment open to the contractor is a variation in cement content above the specified minimum of 175 kg/m^3.

There are no performance requirements with regard to compaction or curing achieved. There is no Section 8 on Quality Control in this specification. Concrete materials are to conform to OPSS 1350.

OPSS 351 Concrete Sidewalk provides for the required properties of the fresh concrete and the 28 day strength of standard cured cylinders. It is silent on who is responsible for the mix design. Concrete is to comply with OPSS 1350. Section 8 on Quality Control only provides for checks on the thickness of the sidewalk concrete by coring. It is noted that the required 28 day strength is only 25 MPa.

OPSS 352 Concrete Steps requires compliance with OPSS 1350 but has no acceptance or performance criteria nor does it have a Section 8 on Quality Control.

OPSS 353 Concrete Curb and Gutter Systems provides for the required properties of the fresh concrete and the 28 day strength of standard cured cylinders. A trial section has to be placed to confirm the adequacy of the contractor's equipment and workmanship. The criteria for acceptance are not stated. There is no Section 8 on Quality Control in this specification. Concrete is to comply with OPSS 1350.

OPSS 354 Concrete Surfacing of Existing Curb and Gutter provides for a repair overlay to be bonded to existing work. Concrete mix criteria include the properties of fresh concrete, the 28 day strength of standard cured cylinders and a minimum cement content. This cement content would be typical of a 30 MPa mix but reflects the 9.5mm maximum size of aggregate specified. Maximum slump is 40mm. Epoxies or cement mortar grout are the alternative bonding agents specified. There are no performance criteria for acceptance nor is there a Section 8 on Quality Control in this specification.

OPSS 904 Concrete Structures requires concrete to conform to OPSS 1350 and makes the concrete mix design the responsibility of the contractor. This is a traditional prescription type specification. It is noted that provisions for the repair of formed surfaces implies acceptance of defects after placing. The Class B finish provided for is not uniformly achieved in practice.

Section 8 on Quality Assurance provides for tests of slump, air content, yield and uniformity of the fresh concrete, and the strength of standard cured cylinders at 28 days. The frequency of testing is determined by the Authority. Extensive detail is given for curing to cover a wide range of ambient conditions and structural dimensions.

OPSS 905 Steel Reinforcement for Concrete provides for quality control of site welding and sampling and testing of prestressing and reinforcing steel.

OPSS 909 Prestressed Concrete - Precast Members provides that while concrete must comply with the requirements of OPSS 1350 it must also be produced by a plant certified or certifiable to CSA Standard A251. Compliance with these certification requirements should guarantee that a high level of quality control is exercised on the materials and workmanship, and that confirmatory records of all QC activity are available. Section 07.07 covers quality control strength testing for release and 28 day strength. Coring is provided for in the event of low 28 day cylinder strengths. Section 8 on Quality Assurance provides for the sampling and testing of steel reinforcement and grout.

OPSS 910 Prestressed Concrete - Cast-in-Place provides that concrete complies with OPSS 1350. For grouting a higher water-cement ratio can be used in long ducts! The cement-admixture-aluminum powder grout mix proportions are specified. Limits for the expansion, bleeding and strength are specified. In Section 8 Quality Assurance field tests are provided for to determine bleeding, expansion and viscosity but no limits for viscosity are given.

OPSS 919 Formwork and Falsework provides no requirements that ensure that the quality of the exposed concrete will be of architectural standards.

OPSS 930 Concrete Overlay - Structures provides for a special concrete and specifies all alternative mixes in complete detail. This is very much a prescriptive specification.

In Section 8 on Quality Assurance procedures are provided which result in quality control of the mix proportions as discharged from the mixer. No performance criteria are specified except the 28 day strength of standard cured cylinders.

3.2.4/Division 10

OPSS 1001 Aggregates-General covers the overall requirements for sampling and testing.

OPSS 1002 Aggregates Concrete states the grading and quality requirements for aggregates for use in concrete. Section 8 on Quality Assurance is concerned primarily with the potential reactivity of aggregates from the point of view of alkali-silica and alkali-carbonate reactions but not slow late-acting silica/silicate reactions.

3.2.5/Division 13

OPSS 1301 Hydraulic Cementing Materials covers the requirements for all CSA-A5 cements plus blended 10-S, 10SM and 10-P cements plus cementitious hydraulic slag and fly-ash. Silica fume is not included.

OPSS 1303 Air Entraining and Chemical Admixtures for Portland Cement Concrete references CSA Standards for approval criteria but modifies the test procedures for quality assurance approval. Superplasticisers are not included. All admixtures used on MTO projects have to appear on the list of designated sources which requires prior approval based on acceptable test data.

OPSS 1312 Latex modifiers for use in portland cement concrete provides a protocol for the evaluation of latex modifiers.

OPSS 1350 Concrete (Materials and Production) is the prime concrete specification for Ministry work. For cement all five CSA A5 types are listed as well as low alkali cement for which no criteria are given. Minimum cement contents are given for concrete strengths up to and including 30 MPa. From a strength point of view these are excessively high at the 20 MPa level and close to marginal at the 30 MPa level. For concrete of 35 and 45 MPa the cement content is to be determined by test to be that which produces durable concrete of the specified strength. No criteria are given for the measure of durability. High strength concrete is defined as 35 MPa or above whereas general practice today places the lower limit at 40 MPa. All concrete is air-entrained.

The section on slump emphasizes the dogma that the lowest slump compatible with placing conditions should be used. For vertical components a maximum slump of 80± 20mm is specified and for horizontal sections (other than paving) 60± 10mm. There are uniformity requirements. The specification provides for the mix design to be provided by either the authority or the contractor. For high strength concrete the same applies, but additional more stringent pre-testing requirements are set out where high strength concrete is used.

There is a lengthy section on Quality Assurance which primarily lists the tests that can be made on fresh and hardened concrete by the engineer. None of the tests relate to the finished in-place quality of the concrete. Provision is made for accelerated testing and in-place strength is judged by field cured cylinders.

OPSS 1352 Precast Concrete Barriers provides criteria for the properties of fresh concrete and the 28 day strength of standard cured cylinders. Volume batching is allowed. Slag and fly-ash are allowed up to a maximum of 70% and 40% of the total cementitious materials respectively. Section 8 on Quality Assurance deals solely with salt scaling tests to determine the acceptability of production units. This raises the question of the suitability of the test for slag and fly-ash mixes, particularly with regard to the curing regime specified. It also underlines the need for specified curing regimes if slag or fly-ash are used in the barrier walls.

3.2.6/Division 14

OPSS 1440 Steel Reinforcement for Concrete,
OPSS 1442 Epoxy Coated Steel Reinforcement for Concrete,
and OPSS 1443 Organic Coatings for Steel Reinforcement state MTO requirements for these materials.

3.2.7/Special Provisions

These are issued for specific contracts and modify the standard specifications.

No 113S02 of June 1985 reflects changes in the Canadian Standards introduced by CSA A23.5 Supplementary Cementing Materials and brings OPSS 1301 into line with current practice.

No 113S09 of June 1988 requires all ready mixed concrete operations to be certified by the Ready Mixed Concrete Association of Ontario (RMCAO).

No 113S06 gives rules for concrete mix designs by the contractor and the submission of samples and test data for the proposed mix.

No 109S14 gives placing and curing requirements for overlays and the calibration of mobile continuous mixing plant using latex.

No 113S10 gives calibration requirements for mobile continuous mixers.

No 109F02 covers the field sampling and testing of concrete. Requires a plan from the contractor in advance of concreting showing curing and handling arrangements for cylinders to comply with CSA A23.2-3C.

No 113S03 of December 1988 provides limits for the use of slag and fly-ash, the latter not to exceed 10% of total cementitious material, and slag or slag plus fly-ash not to exceed 25% of total cementitious material. A warning on potentially lower early strengths is given. The option to use supplementary cementing materials and responsibility for mix designs are the contractor's. This special provision overrides OPSS 1352 with regard to limits on slag and fly-ash content.

No 113S04 of August 1989 introduces a bonus/penalty system for use on contracts for structural concrete where performance is judged by the compressive strength of standard cured cylinders. The potential penalties are much higher than the potential bonuses.

3.3/Supervision

Insofar as Quality Assurance (QA) is concerned this is provided for at three levels as follows, namely the site staff and quality assurance officers in the Regions, and the EMO staff in head office. Each Region has a number of quality assurance officers on the staff of the Regional Director. For concrete, Central Region has four, Southwestern and Eastern two, Northern one and Northwestern two (who also cover other materials). Not exactly an army. These QA staff carry out an advisory and surveillance role on all the new construction and repair contracts in their area. They interact firstly with each project supervisor and secondly with the site inspectors who apply QA procedures on site. Behind both these two levels is the engineering materials office with staff available on a visiting basis to trouble-shoot and, where necessary, carry out investigations of materials problems. Apart from standard concrete cylinders all other QA tests on materials are made by the Regional Laboratory or Engineering Materials office, depending on capability on samples taken by the site inspectors. The flow chart can be illustrated as follows in Figure 1:

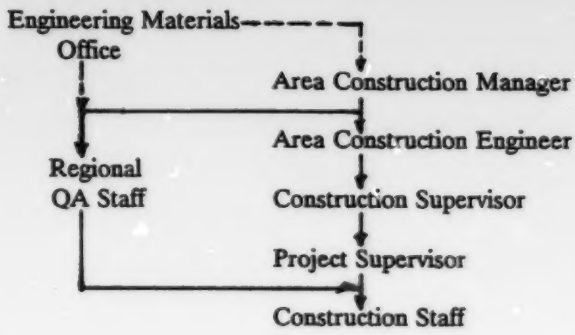

Figure 1. QA Staff Interaction With Site Staff

3.4/Testing

Current Ministry policy with regard to testing concrete is to contract annually on a regional basis with a CSA approved laboratory for the curing, capping and testing of standard cured 150mm diameter by 300mm cylinders. These are cast by others and delivered to the laboratory. Apart from having a suitable CSA approval, laboratories have to be on an MTO approved list which is revised annually. Inclusion on this list depends on participation in round-robin cylinder tests organized by the Ministry. Each laboratory's test results are compared to the test population mean, and in-test and between laboratory variation. Continuing approval is predicated on acceptable results in this annual test.

On nearly all contracts the quality assurance test cylinders are cast by CSA certified independent testing laboratories hired by the contractor. If the concrete supplier has ACI certified Field Technicians the supplier can provide this field testing. Field testing of fresh concrete includes slump, air content and temperature measurements, and the casting of standard cured cylinders.

Applying current specifications the laboratory testing for the Ministry can be, but should not be the one testing for the Contractor. It is understood that this change will be made in 1991.

3.5/Concrete Placement

OPSS 904 covers all aspects of concrete placement. It incorporates traditional good practice requirements, but is not exhaustive since pumping is not covered, nor is there any mention of cold joints. Field observations suggest that on occasion the scheduling of concrete deliveries is such that cold joints do occur with consequent surface defects visible on the exposed concrete. See figure no. 1.

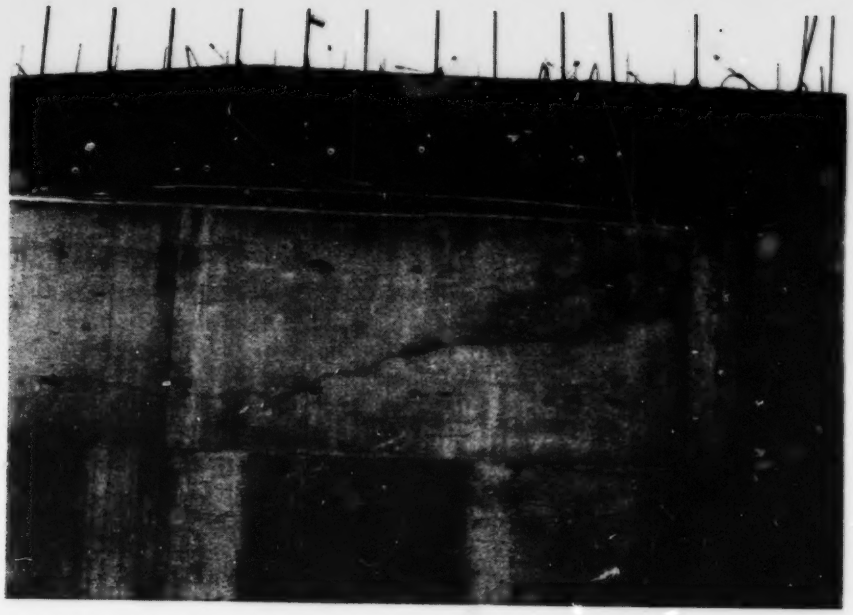

Figure No. 1. Cold Joint

3.6/Grouting

Grouting for both pre-cast and cast-in-place prestressed concrete is covered by OPSS 910. The grout mix proportions are specified and limits are given for bleeding, expansion and strength. Viscosity tests are indicated as part of QA testing but no limits are given nor is the test procedure identified, though presumably the old Corps of Engineers flow cone test is assumed.

Grouting procedures specified are typical of traditional practice.

3.7/Paving

Very few Portland Cement Concrete (PCC) pavements have been constructed in recent years, either exposed or with an asphalt wearing course. Historically the riding quality of concrete pavements has not been acceptable to the public in Ontario and the economics have not always been favourable.

With the current exposed concrete pavement contract on Highway 115 and plans for Highway 407 the MTO is continuing its policy of maintaining a nucleus of a concrete paving industry.

4.1/Cement

Most cement used in Ontario is manufactured and marketed by a small number of cement companies. With one exception, the major companies are subsidiaries of foreign multinational companies[2]. There is significant vertical integration in the materials supply and concrete industry. For example:

COMPANY	CEMENT PLANTS	CEMENT DISTRIBUTION TERMINALS	CONCRETE PLANTS	AGGREGATE SOURCES
St. Lawrence Cement*	5	33	56	29
Lafarge Corporation*	14	74	116	60+

Similarily St. Mary's Cement owns significant producers such as Canada Building Materials (37 plants) and KW Blair, while Lake Ontario Cement owns KVN and Premier.

* 1989 Annual Reports.

It has been estimated that the cement companies control between 75% and 92% of the ready-mixed concrete production in Ontario. Some cement manufacturers also market chemical admixtures and supplementary cementing materials. The capacity of the Ontario cement plants in 1987 was just over 7 million tons of clinker[2]. While most cement used has been of Canadian manufacture the opening of a new import terminal on Lake Ontario may change this situation. Idorn says[3],

> "Traditionally, cement has been a product of local uses, and the sale and distribution have belonged to the producing industry. This is due to the excessive transportation costs of such a powdery product, and is also a consequence of the widespread availability of raw materials for cement and concrete. Recent development in transporting masses of powdery materials by rail, trucks and large, oceangoing bulk carriers has fundamentally changed the cement trade. It is now increasingly a purchase and sale commodity. Even traditionally leading cement industry companies in North America, Europe, and Asia are now using their own productions as part of a total stockage of whatever is available elsewhere at profitable prices."

The introduction of a wild card player into an otherwise closely controlled market could create both opportunities and potential problems.

Experience has shown that cement supplied from other countries may not be in accordance with the specified type, and in some instances adulteration has occurred in transit. Ontario cement has proven to be reliable and consistent in quality. New measures will be required to ensure that imported cement meets the same criteria.

Of particular interest is the question of low alkali cement. A significant percentage of Ontario

aggregates are potentially reactive. The actual and potential damage attributable to the three types of alkali reactions present in the province is of major concern to the Ministry, as indeed it should be to all users of concrete. Selection of virtually non-reactive aggregates is not possible in all areas; transportation costs to bring such aggregates to projects in areas of potential reactivity is expensive, and MTO policy does not allow the use of supplementary cementing materials in sufficient quantity to control deleterious expansions.

It would seem fundamental to return to the technically simple and sure way of controlling these reactions, and specify low alkali cement as an alternative for all concrete in areas where there is even a slight possibility of an eventual expansion due to alkali-aggregate reactions (AAR). It is suggested by the cement companies that the production of low alkali cement is expensive and poses environmental problems. Idorn says[3],

> "Cement production will also become the victim of resource problems, if the demands on low alkali cement for prevention of alkali-silica reactions increase. This is because it will mean increased disposition of alkaline kiln dust, which is a loss of the resource material, and an unacceptable hazard."

Notwithstanding this, it is reported that such cement has been produced recently in Ontario on a potentially large scale with no apparent deleterious environmental effects and perhaps at a surprisingly low cost. Such cement is also produced in Canada for sale in the U.S.A. It would seem that this is one area in which the Ministry and the cement industry could work together beneficially to establish what can be done having regard to the economic and environmental concerns of the Province. Alternative uses may be found for surplus kiln dust.

There have been differences of opinion between the Ministry and the cement industry with regard to the performance and variability of cement. A number of internal and external reports have been commissioned by the Ministry relevant to this topic. In 1978 Chojnacki[4] found only a 7.4% variation in the 28 day concrete compressive strength produced by 6 brands of Ontario cement and no significant differences in the salt scaling performances of 25 MPa concretes made from them or in setting time, bleeding or shrinkage. The results are shown as follows:

Brand	28 Day COMPRESSIVE STRENGTH MPa
A	42.0
B	43.1
C	38.5
D	37.1
E	36.8
F	36.3
$\bar{X}$	39.0
s	2.89
V	7.4%

In a further study in 1981 Chojnacki[5] found that the variability of the 28 day compressive strengths of concrete made from 7 cements was 4.4% or less. Different cements had widely different requirements for air-entrainment however, leading to concern about the quality of in-place air void systems. In 1987 Newell et al[6] found a considerable variation in the strengths of 20 MPa and 30 MPa concretes. All concretes tested had good durability to freezing and thawing but some failed MTO salt scaling tests. It was thought by the industry that these failures may have been due to specimen surface preparation or the precision of the test itself.

A 1988 laboratory study by K. Rose et al[7] made a statistical analysis of factors causing variations in concrete quality. Some were tentatively identified but this approach has not been followed further.

Two test programmes were carried out for the CPCA by Trow Inc.[8,9] Phase I was intended to establish within-laboratory and between laboratory precision statements for the salt scaling test procedure. The tests showed wide differences between the two laboratories involved. While the total losses were in all cases less than half of the limit allowed by MTO the test concretes had particularly good air-void systems, significantly superior to the minima required by MTO and good practice. Further work would be required to determine the multi-laboratory precision of this test. The Phase II programme concretes also had exceptionally high quality air-void systems and total losses were very low. Some reservations were expressed about the test procedures and suggestions made for improvements.

4.2/Supplementary Cementing Material (SCM)

Granulated Blast Furnace Slag, Fly-Ash and Silica Fume are readily available in Ontario and, except for Silica Fume, are in extensive use on Ministry projects. Their use alone or in combination can be highly beneficial in the production of high performance concrete. The advantages are:

- Economy.
- Control of alkali-aggregate reactions.
- Reductions of heat development.
- Greater impermeability.
- Higher resistivity.
- Superior microstructure.
- Higher strength.
- Better volume stability (shrinkage, creep and modulus).

Ministry use to date has been limited by internally generated test data and field perceptions of reduced durability at high enough cement replacements to provide optimum benefits[10,11,12,13]. Use to date is in fact primarily driven by supplier interest and economy.

4.3/Chemical Admixtures

4.3.1./General

The main current developments in the local admixture industry appear to be:

Non-chloride accelerators.
High range water reducers with extended slump retention times.
Stable air-entraining agents suitable for all slump ranges.

Other developments are water based membrane curing compounds, anti-wash out admixtures as an alternative to discarding the residue in a truck at the end of the day, and anti-corrosion bonding agents. Most manufacturers have a range of repair materials, and some new ones are being developed.

While not new, silica fume-high range water reducer combinations suitable for high resistivity and low permeability overlays are available.

Other developments of particular interest in this study are a product to improve surface finish, and one to increase workability or more accurately ease of compaction without increasing slump. The former would help meet the target of better surface quality and contribute to both durability and aesthetics. The latter would contribute to improved compaction and therefore durability, and would be a step towards making the Contractor's task easier. The imputed properties of the latter admixture also point out the need for an improved way of measuring workability.

All manufacturers have research and development capabilities of widely different size and scope. At least one is party to the financing of an industrial research chair at a Canadian University. Here the compatibility problems of cement and admixtures are being addressed. Already identified is a potentially major effect of mixing water chemistry that could provide a key to the solution of the cement/admixture compatibility conundrum.

4.3.2/Air Void System

A cornerstone parameter in achieving durability is the achievement of a satisfactory air void system in the hardened concrete. Current practice is to specify the use of a chemical admixture that has produced satisfactory performance in a stylised programme of laboratory tests, and then check that the air content of the concrete at the time it is delivered to site meets specified limits.

This procedure has been proven by many expensive failures in durability not to work reliably. It would seem axiomatic that since a certain quality of air void system in the hardened concrete is an essential quality of the product purchased, then the purchaser is entitled to receive what is paid for.

A number of recent developments have addressed this issue. Canadian Standards S463-88 and A23.1-90 both[14,15] require proof that an adequate air void system is being achieved on a site-by-site basis. This move has met with considerable opposition from the ready-mixed concrete industry. The objections to assuming this additional responsibility have centred on two main areas. The first is the unreliability and excessive variation in the test procedures used to determine the air void system, and the supposedly excessive variation in results between testing laboratories.

The latest round-robin series of tests to determine interlaboratory correlations of air void systems, carried out from 1987 to 1989, was the fourth such test series made by the Ministry, and involved eight laboratories.

In ASTM C457 up to the 1990 edition[16], variability values are only given for air content and the Difference Two Standard Deviation Limits (D2S) are given as those which are the maximum that should occur between two tests by the same operator.

In the Ministry test the following values were obtained for tests in the range of air contents that would be acceptable on site (eliminating results from one laboratory that was an extreme outlier):

Air content %	5.56	7.89
Standard deviation %	0.47	1.17
Specific surface mm^{-1}	36.17	39.23
Standard deviation mm^{-1}	5.39	9.23
Spacing factor mm	0.13	0.09
Standard deviation mm	0.03	0.02

The results of the test series show that the inter-laboratory precision of the test is inherently lower than is desirable. It is thus necessary to improve the test procedures used, and increase the frequency of inter-laboratory testing. It would also be preferable to have the tests made by laboratories without them knowing that they are being checked. It may also be necessary to restrict testing to a small number of the better equipped testing laboratories who are shown by a meaningful MTO evaluation to have the real capability and experienced staff to make this test.

There is room for comfort in the above data, however. Taking the worst case data for spacing factor the D2S value derived from the above data would be as follows:

Spacing factor = 0.13 + 2.83 (0.03)
= 0.21 which is not quite acceptable.

The second, and apparently reasonable, objection is to the fact that the placing and compaction methods of the contractor, which are outside the control of the concrete supplier, can adversely affect the air void system. While there is some merit in these arguments they are not completely valid. It is practice world-wide when designing concrete mixes to aim for a strength higher than the specified strength. This allows for inherent variation in both quality control of the ingredients and sampling and testing. A similar approach may be possible with the quality of air void systems, with the supplier providing a higher than specified quality at the point of discharge in order to ensure an acceptable quality, despite a degree of degradation resulting from the contractor's placing and compaction operations. Pigeon[17] has already suggested this, and it is worth further consideration. Alternatively, the admixture industry must develop and market chemicals that produce more stable air void systems in the freshly mixed concrete that are resistant to change during placement and compaction.

It would therefore seem that a modest improvement in testing techniques plus the adoption by the supply industry of an overdesign approach to the quality of air void systems may be all that is needed in combination with the use of more stable air-entraining agents.

With regard to testing procedures, the Ministry already operates a once a year interlaboratory correlation programme with laboratories that wish to do testing on Ministry projects. This scheme could, with advantage, be refined with specific performance limits imposed for qualification. Such limits could also form the basis for air void system design procedures on the lines discussed above.

More urgently in the field of testing is the need for earlier confirmation that the concrete supplied has, in fact, the quality of air void systems specified. This has long been a concern of the Ministry and requests for research proposals in this area were a common annual feature. Much is finally being done in this area, mainly as part of the Strategic Highway Research Programme. Cornell University is researching revibration and variable pressure concepts, and Michigan University is evaluating the Danish "Champagne" test using laser measurements on nitrogen frozen cores of fresh concrete. The New Jersey Institute of Technology has patented a method using fibre optics. On the Storebaelt road project in Denmark another Danish procedure based on the different rates of rise of different sizes of air bubbles in a column of fluid is in use as a routine quality control test.

Substantive success with any of these procedures would go a long way to screening out fresh concrete with inadequate air void systems on arrival at site. Stable air void systems will still be required, to withstand handling, and the resolution of the problem of ensuring good air void systems in all concrete will require a multi-disciplinary approach.

4.3.3./Air-Entraining Agents

The obvious answer to the problem of attaining a satisfactory air-void system is the use of an admixture which produces a stable air-void system in the hardened concrete at all slumps and despite the effects of transportation, handling and compaction. It is claimed that some recently available stable air entraining agents will in fact do this. Some problems have been encountered in their use. Re-tempering with water after initial mixing can produce undesirably high air contents. Such a control problem is worth solving if the performance of such agents is in fact as claimed. The other possible problems to their adoption are cost and the complication of adding another admixture dispenser to existing batch plants. With regard to costs the percentage of the cost per cubic meter of concrete to provide such an air-entraining agent cannot be of consequence let alone the cost of that concrete in place or the cost of repairing or replacing it if it turns out not to be durable. Furthermore the adoption of such admixtures would provide a lead to the rest of the construction industry, and would surely be followed with overall benefits to the durability and service life of the whole of the infrastructure.

4.4/Aggregates

At any one time over 400 sources of aggregates are in production in Ontario[11]. Total supply is adequate to meet industry needs for concrete production. In most areas aggregate suitable to make concrete meeting all Ministry specifications physical test requirements are available within an economic haul distance. Crushed stone is available with the ability to make concrete with specified strengths up to at least 85 MPa and potentially suitable for strengths up to 100 MPa[18].

The predominant problem with aggregate supply is that a significant proportion of the deposits are potentially prone to alkali-silica, alkali-carbonate or late/slow acting alkali-silica/silicate reactions. This is exacerbated by the trend to higher alkalis in Ontario cements.

A number of alternative strategies are available to control this problem[19]. Non-reactive aggregates can be transported from other areas but this can be very costly. Existing aggregates can be beneficiated physically and quarries can be operated selectively. Supplementary cementing materials can be used to control alkali-aggregate reactions, but fly-ash and slag would need to be used in significantly higher replacement percentages than currently allowed by Ministry specifications. Some Ministry research into the use of higher percentages has led

to concerns about durability, and the present Ministry attitude to this solution is somewhat negative. Silica fume is not covered by any Ministry specification. Finally there is the option of using low-alkali cement, and this is discussed above in 4.1.

One practical problem related to the control of these reactions in the past was the lack of a reliable rapid test with low inter-laboratory variation. The resolution of this problem has been achieved and no more work will be required.

It has been recognized in the past that concrete subjected at an early age to a high temperature curing cycle may form unanticipated ettringite and suffer deterioration from internal sulphate attack[20]. With the expanding use of concrete ties for GO-Train routes and of other pre-cast concrete components and a possible trend to higher strength concrete this is a potential problem and a solution needs to be sought.

The need is discussed elsewhere for an improvement in the test procedures to determine the salt-scaling resistance of concrete, and in doing this aggregate effects would have to be taken into account.

The Ministry has researched the use of granite curbs[21]. Suitable materials are available. As an alternative to granite curbs wholly of stone it is possible to use the stone in question as an aggregate to produce ultra-high strength concrete curbs with similar durability. This approach has been used in Quebec to produce concrete rollers for the paper industry where stone rollers were used previously. As noted elsewhere concrete up to 135 MPa has been used on Norwegian pavements and is highly resistant to wear by the metal tire studs widely used there.

4.5/Reinforcement

Except in the wide scope of its use of epoxy coated bar current Ministry practice is conventional. It has been suggested that there might be benefits in the use of high strength steel of 500 MPa yield strength, and there is a trend to this in Japan[22] and Europe[23]. It has also been suggested that the bond resistance of epoxy coated bars could be improved by a change in the design of bar deformations. The effect of different bar deformations on bond has been previously researched[24] and the Reinforced Concrete Research Council recently invited research proposals in this area with a closing date of June 1st, 1990[25].

In visiting construction sites during this project it was noted that minimum concrete cover in some critical areas was not always in accordance with design. QA staff advised that subsequent to placing concrete a covermeter check is carried out on the hardened concrete, the data recorded on a standard form and a percentage compliance calculated on a statistical basis. In this respect a procedure already exists which could become a performance standard. It is noted

here that NIST is currently evaluating covermeter performance and this is one of many investigations worth tracking.

Furthermore it was noted that uncoated steel is sometimes exposed for a long time before concreting resulting in significant rusting of the bars and staining of adjacent concrete.

It was also noted that there seems to be little standardization of reinforcement detailing. On one interchange site the reinforcing details of two similar piers were very different, allowing no economy of scale to the steel supplier. Furthermore some bars could not be installed as bent to bar lists. It would be preferable for suppliers to produce such bar lists. In the instance cited epoxy coated bars already bent had to be unbent and then rebent on site to fit.

4.6/Concrete

4.6.1/Quality Assurance

At the moment the only routine quality checks on concrete are limitations on age after batching, temperature on arrival on site, slump and air content and the compressive strength of standard cured cylinders. The tests made on fresh concrete are intended to ensure that the ultimate quality will be acceptable and the only measure that the concrete is acceptable are the test data for test cylinders.

A summary of these for 1988[26] and 1989 are interesting.

Table A

Summary of Tests by Region

REGION	1988 NUMBER OF TESTS	1988 % BELOW SPECIFIED STRENGTH	1989 NUMBER OF TESTS	1989 % BELOW SPECIFIED STRENGTH
Central	1146	6.8	781*	6.7
Southwestern	600	8.3	514	5.8
Eastern	585	8.2	425	1.6
Northwestern	224	14.7	139	2.9
Northern	332	11.1	337	8.0
All Regions	2887	8.5	2236	5.5
All Regions (Under Performance Specification)	643	6.7	495	1.2
All Regions (Without Performance Specification)	2244	9.0	1741	7.2

* Not all results submitted.

The percentage of test results below specified strength in 1988, and to a lesser extent 1989, are surprising and higher than would be found on a well controlled site in the private sector. With the exception of Central Region all regions showed an improvement from 1988 to 1989. While all the results from 1989 were not available at time of writing, a summary of the 1988 contracts with 30 or more test results is also of interest.

Table B

Test Data for Contracts With At Least

30 Sets of Results

REGION	CONTRACT	25MPa				30MPa				35MPa			
		N	$\bar{x}$	S	V	N	$\bar{x}$	S	V	N	$\bar{x}$	S	V
Central	3									35	45.7	4.15	9.1
	21					45	35.7	7.95	22.3				
	26					78	34.9	5.18	14.8				
	30					205	37.7	4.38	11.6				
	32	42	32.9	4.04	23.3								
Southwestern	3					55	33.8	4.78	14.1				
	7					40	34.7	6.18	17.8				
	9					31	34.9	3.60	10.3				
	14					124	37.0	4.75	12.8				
	6	30	35.1	3.91	11.1	122	37.3	4.08	10				
	7					38	38.4	5.98	16.4				
	11					39	35.6	4.55	12.8				
Eastern	16					44	36.3	3.43	9.5				
	17					46	32.0	7.08	22.1				
	18	43	34.6	4.49	13.0	55	36.2	5.15	14.2				
Northwestern	3					32	30.6	2.40	7.8				
	6					30	33.9	3.52	10.4				
	11					30	33.5	5.22	15.6				
Northern	5					36	31.2	5.71	18.5				
	7					35	37.0	4.12	11.1				
Performance Contracts	5					34	34.8	4.5	23.0				
	2									33	38.2	3.2	8.3
	3									31	37.3	2.4	6.4
	6					37	38.0	5.3	13.9				
	7					66	40.2	4.5	11.2				
	8					61	32.9	5.8	17.6				
	10					107	38.0	4.5	11.8				
	13									31	45.7	4.3	9.4
	14					69	35.1	5.0	14.2				

The biggest improvement of all came from the performance contracts, which may reflect the experience gained by contractors in meeting the requirements in this approach. If anything can be concluded from this it is that superior results flow when the contractor can exercise his expertise.

The data in Table B shows that control is consistently better for high strength concrete. It also shows that for the other mixes a coefficient of variation of 10% or lower was only achieved twice in 27 contracts. The overall picture, except for the 35 MPa is not one of good control. It is also curious that Central Region supplied by the most sophisticated segment of the ready mixed concrete industry in Ontario was not one of the better performers.

4.6.2./Standards

It is suggested that there are benefits to all concerned if a great degree of uniformity can be achieved between the standards specified by the Ministry and the CSA National Standards. From the point of view of the supply industry the fewer inconsistencies and the fewer different requirements the better. The European Economic Community (EEC) is in the process of standardizing concrete standards[27], and has a target of the end of 1991 in order to meet the needs of a common market starting in 1992. It would seem desirable and possible to standardise further requirements for concrete in Ontario. With the publication of CSA A23.1 and A23.2 in March 1990 it would be opportune to review this now.

4.6.3/Mix Design

The ideal concrete mix is Kunashima's "Dreamful" concrete as defined at the National Institute of Science and Technology (NIST) Washington Workshop in May 1990. This forgiving concrete, which is intended to compensate for poor construction practices, is intended to have the following properties:

Virtually self compacting even in areas of congested reinforcement. Little vibration required.

Extremely cohesive and resistant to segregation during handling, placing and compaction.

Minimal cracking at early ages due to shrinkage and thermal effects.

Satisfactory strength.

Low permeability.

If concrete mixes can be non-segregating and virtually self-compacting the chances of achieving a consistently high quality structure are better. The technology exists to do this so why would we not do it?

With some basic work on mix design and an appropriate specification such concrete could become a standard for the province.

4.6.4./Covercrete (Cast-in-Place)

If the concrete is of adequate quality in relation to the amount of cover specified by MTO design standards then the intended service life will be achieved.

What is the optimum quality for highway structures? Do the strengths specified for structural concrete and for other concrete exposed to severe environmental conditions such as highway barriers achieve this optimum quality?

If 25 and 30 MPa are the common strengths with a significant amount of 35 MPa concrete, do these requirements alone or with the other parameters specified by MTO achieve the optimum concrete?

The current trends in the search for durable concrete would suggest that the need for impermeability leads inevitably to concretes that are much stronger than required by current MTO practice. Materials such as silica fume and other supplementary materials and superplasticising chemical admixtures are the materials of choice to achieve these concretes. Such concretes are inevitably significantly more expensive than the structural mixes presently in use. Is an increase in concrete cost justifiable? Are there economies in design possible by the use of higher strength concrete that would offset these increased materials costs? Data presented at many seminars by the Portland Cement Association (PCA) and the Canadian Portland Cement Association (CPCA) representatives would suggest that there is. Is this true for all MTO structures, or some of them, or for special ones? Would it increase the flexibility of design options open to MTO designers?

From a life cycle cost point of view is an improvement in concrete quality necessary, and if so, what are the life cycle cost benefits that would justify the extra concrete cost on this basis?

4.7/Shotcrete

There are three important aspects of the shotcrete repairs made by the Ministry. The volume of shotcrete placed in any one day and in total on a contract is relatively small. The plant used is that traditionally used to produce large quantities of shotcrete. Batching is a crude process carried out on site at a very low level of quality control. There is plant available more suitable for the production of small quantities of shotcrete. There are also pre-mixed, pre-bagged shotcrete mixes available on the market, and any specific Ministry mix could be produced in the same way.

To date, Ministry practice has been to use mainly latex modified shotcrete. This has dubious durability in severe exposure conditions and while theoretically durable, has presented major problems in service. Significant thicknesses cannot be applied in each layer, and strength is low; finishing is difficult and cracking prevalent. Delamination is common to the point that it could be termed a normal characteristic.

Since shotcrete is an important option in restoring the structural strength, protective cover and profile of deteriorated structures, a higher performance shotcrete is required.

As a result of the study on shotcrete commissioned by the Ministry, a trial application of a silica fume shotcrete was proposed. It is understood that an 8% silica fume mix was proposed[28].

The trial has been made and appears to have been successful. Nevertheless, the potential importance of this material for rehabilitation warrants further consideration before it can be fully and confidently specified for Ministry contracts. A matrix for further investigation is shown in Appendix 5[29]. In an overall programme to improve shotcrete quality, discussions with industry representatives should cover plant improvements such as those reviewed at the Fifth Engineering Foundation Congress on Shotcrete Support of Underground Openings at Uppsala, Sweden, June 1990.

4.8/Grout

One very important reason for producing a non-bleeding, non-shrinking thixotropic type of grout is the prevention of voids in grouted ducts. Previous investigations have shown less than perfect grouting to be wide spread. In one investigation in the U.K.[30] over half of ducts examined contained voids; some to the point that tendons were exposed. In a Japanese survey[31] voids were found in 35% of the ducts examined with 10% large enough that the ducts were only half full at the void location. Recently an investigation was carried out by the TRRL in the U.K.[32] to determine why voids are formed, and how to ensure that they do not occur. Many current site deficiencies were identified that relate primarily to inadequate quality control in placing and grouting practice. The quality and the control of the grout itself was also considered a major factor. Experiments were carried out starting with laboratory tests, then preceding through trials on an 8m long mock-up to a 45m mock-up incorporating various duct profiles and vent locations. The properties of a suitable grout were stated as follows:

"i) Fluidity suitable for pumped injection.

ii) Initial setting time sufficient to cover the planned period from mixing to completion of the grouting

operation. The operation is not complete until voids have escaped from the vents and this will be some time after completion of the injection. A margin for unexpected delay must also be included.

iii) Cohesion sufficient to suppress bleeding."

The protection of prestressed tendons is a high priority project with the U.S. Federal Highway Authority (FHWA)[33]. The current 1988 to 1993 project budgets a total of $2.2 million for research and development of all aspects of prestressed concrete protection. Of this $400,000 covers protection of steel in ducts and regrouting of partially filled ducts. It is clear that while bonded tendons in properly grouted ducts have in the past been considered well protected, it is now considered that past practice is inadequate in today's severe de-icing salt environment. That significant sums of money are to be spent to research suitable materials for re-grouting where voids are present in ducts highlights the deficiency of past practice and the need for more foolproof grouts.

Current Ministry policy specifies a Type 30 cement, non-chloride water reducer and fine aluminum powder. Maximum water cement ratios allowed are 0.50 for cables less than 45m long, and 0.55 for cables 45m long or over. This allowance of a higher water-cement ratio for long ducts seems illogical. The degree of protection required for a long cable is the same as a short cable. It also demonstrates a fallacious way of solving the need to have a grout that will flow easily into the ducts under reasonable pressure. Making the grout wetter is not the optimum solution.

Ministry concern for the protection of prestressed tendons has led to two research programmes dedicated to the improvement of grout and grouting techniques. The first study concluded that the use of Type 10 cement, a silica fume content between 10% and 15% and a superplasticizer was found to produce a grout with far superior protective qualities, such as chloride impermeability and electrical resistivity[34]. The report also made two very significant recommendations. One was that once a standard optimum grout is determined the dry ingredients should be supplied in prebagged, premixed form. It is unconscionable that in 1990 the crude measurement of ingredients in the field is accepted. If the quality and proportions of the solid materials are pre-established, water addition can be accurately controlled in the field given the will to do so. The other recommendation related to a field trial. When it is established that the optimum grout can be reproduced repetitively, a field trial is essential. It is noted that it has been suggested that plastic ducts may provide better corrosion protection than metal ducts. When a field scale trial is done it could incorporate both metal and plastic ducts. A number of suppliers are developing plastic ducts.

Unfortunately, incompatibility of materials in the recommended grout led to its stiffening on site, which would adversely effect the quality of the finished work. A second research project was therefore initiated to investigate this problem and further optimize the grout mix[35]. The second investigation identified a cement superplasticizer combination which did not result in early and premature stiffening, and identified cement superplasticiser incompatibility as the cause of stiffening, but did not identify the nature of that incompatibility.

One major contribution of this study was the development of a target specification for post-tensioning grout. This provides the basis for further development which is warranted.

It would be nice to identify the cause of the cement admixture incompatibility. The knowledge would provide a certain way of specifying acceptable and durable combinations of cement and admixtures. However, the identification of a compatible cement admixture combination in the second investigation provides a basis on which further practical work can proceed, either as part of an investigation of cement admixture compatibility or as a separate programme.

It has been shown that high speed shear mixing can, of itself, increase the efficiency of a mix, and such mixing is the key to optimization of any given mixture. While some grout mixers are designated as shear mixers, it is considered that any new test program should start with an investigation to optimize mixers configuration, speeds, and mixing times. Once the optimum grout is developed a full scale mock-up trial should be made under controlled laboratory conditions before proceeding to a field trial. The quality of grout is too important not to use accurately pre-bagged mixes, and apply better quality control specifications on site.

4.9/Formwork

The design and erection of formwork is covered by OPSS 919 Construction Specification Formwork and Falsework of December 1984. This specification covers design requirements, materials and construction. It is noted that for exposed surfaces the plywood used should have an approved resin bonded finish or equivalent. This is not being uniformly enforced, as can be seen by the wide range of colour of plywood on site and in the exposed concrete. The section on Construction requires that forms be mortar tight to allow full compaction of concrete without leakage. Re-use is allowed if the result is equal to that produced by new material. No criteria are detailed as to how this judgement is to be made. Site evidence is that it is not.

It is essential to the production of uniformly high quality durable concrete that forms do not leak. As a public agency it is also important that the Ministry concern itself with the aesthetic aspects of the environment.

> "In the present age of heightened public awareness, bridge design engineers can no longer be allowed to limit their activity to static calculations and monitoring of construction. The public will not permit us to create unattractive structures. After a bridge is constructed it actually changes its particular part of the environment for 50 years or longer. There is a growing perception that ugly bridges actually are a form of pollution and in fact seem to breed discontent and despair".[36]

There are therefore two reasons why an improvement in formworks standards should be sought. Firstly there is economic benefit in improving the service life before repair of existing designs made with currently specified qualities of concretes. Secondly, the improvement in appearance that could be achieved would improve the visual quality of the environment for everybody. Other nations have long taken the opportunity to build into their highway structures architecturally pleasing finishes. Fling said,[37]

> "Concrete is Beautiful - this seems to be the European motto. Concrete has been designed for esthetic appeal by intent rather than by accident. Highway bridges at grade crossings present a graceful profile; ugly bridges don't exist and not all bridges appear the same. Many variations are used even in the same district and same highway system. When the terrain presents unique problems, the Germans and Swiss make the most of it with sleek, daring designs. Soaring buttresses, isolated tapered piers, and unusual shapes make European bridges quite fascinating.
>
> Retaining walls contrast most sharply with American practice. Walls formed with plain, unadorned plywood are almost never exposed to view. Board marking is most common but other textured liners, exposed aggregate, and painting are also used. Rustication joints and form tie spacings are planned, not haphazard".

Examples of the use of this approach are illustrated by a set of slides produced by the Cement and Concrete Association of "UK Highway Structure Finishes," two examples of which are shown in figures 3 and 4. Bridge structures are often visually attractive as an inherent consequence of the mathematics of design. Their appearance can be enhanced by carefully selected and executed finishes.

If a policy is adopted to improve visual quality for the two reasons cited above, then high quality formwork will play a major role. While high quality formwork will not of itself ensure a high quality finish such a finish cannot be achieved without it.

The materials already specified are of high quality. By observation during site visits, forms used in major components are seen to be well engineered and of expensive and robust design. What is needed to make them grout tight is, in most cases, a matter of detail. This would involve the development, adoption and specification of mandatory details to seal forms at all closures. In most cases appropriate details have already been developed elsewhere, and individuals are available to assist in further development where needed. It is anticipated that any increase in

forming costs predicated by the introduction of higher standards would soon be seen to be offset by lower costs in finishing and repairing concrete.

The above comments are intended to cover columns, piers, abutments and wing walls. A more difficult surface to finish well is the bridge soffit, particularly those of composite steel bathtub girder and concrete design. It is in a practical sense very difficult to seal all interfaces between steel and timber. The effort should be made, although this might be a lower priority than the finish of other bridge components.

Figure No. 2

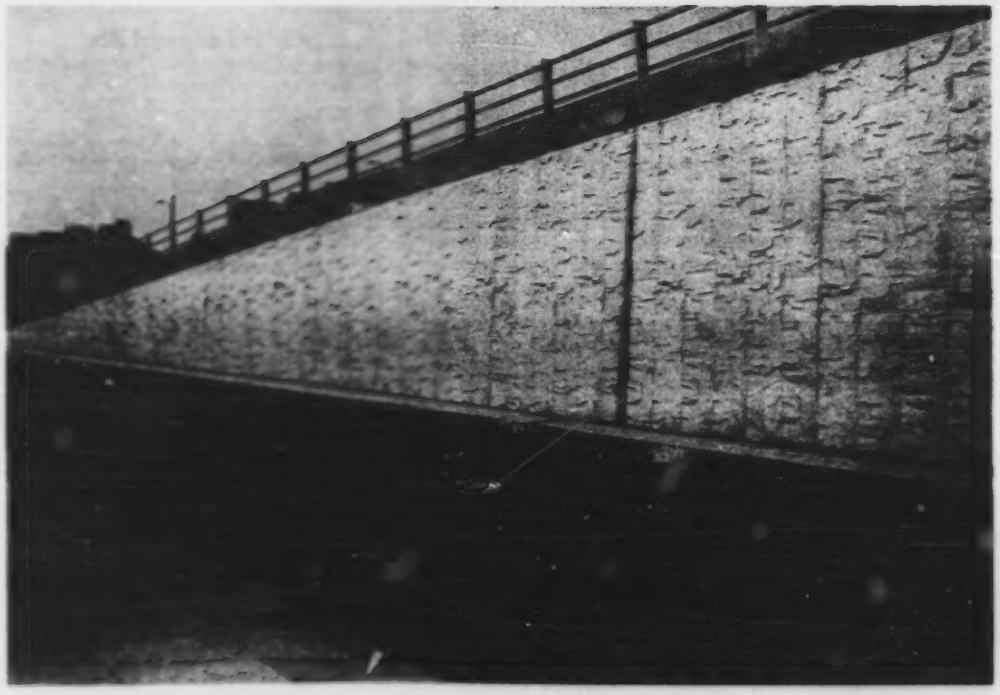

Figure No. 3

Two other developments in formwork are worthy of note. Controlled permeability formwork (CPF) is being used to improve both the quality and appearance of the surface concrete. Smart formwork using an Advance Maturity System (AMS) type approach can monitor the maturity of the concrete and temperature differentials between the concrete surface and ambient temperature for control of insulation and cracking.

4.10/Repair Materials

Shotcrete as a repair material has been dealt with in 4.7. The choice and application of suitable repair materials presents one of the biggest challenges to an engineer involved in rehabilitation. There are so many products. New ones are introduced constantly. Formulations change without notice, and information on service life is, in most cases, unavailable. The needs for pavements and structures are different. In pavements the prime need is for a concrete for full depth repairs which can be opened for traffic in a few hours. Recent use of exotic cement systems has shown variable and unreliable results.

For structures there is no practical way that comprehensive acceptance tests can be made on all the proprietary products which reach the market.

Significant investigations are underway under the SHRP programme, and elsewhere in the world. An order of magnitude step forward in knowledge in this area can be expected in the next few years. In the meantime, a made-in-Ontario solution could be sought for interim improvements pending the outcome of more extensive and expensive solutions. This is an area where a performance type specification may be the easiest solution. Criteria for the quality of preparation and for the characteristics of the hardened repair material in-situ could be specified. The latter could include bond, stability, freeze-thaw durability, resistivity and permeability.

5/Current International Practice and Research

5.1/General

The following is not an exhaustive review of all the concrete research currently being undertaken around the world. That would be beyond the scope and resources of this report. It reviews, rather, activities that are current in countries known to be active and advanced in research relevant to the use of high performance concrete in highway construction.

5.2/Canada

In Canada several major research programs are current.

The Network of Centres of Excellence on High Performance Concrete comprises nine principal researchers from seven universities plus two industrial partners. This programme is funded for $6.4 million over four years commencing July 1st, 1990.

The areas of research of potential application to highway structures are:

Reducing permeability and porosity.
Freeze/thaw and de-icing salt resistance.
Thin overlays.
Materials selection criteria.
Investigate high strength reinforcement.
High performance concrete as a granite substitute.
New concrete mixing techniques.
High performance grout injection techniques.
Long term durability of high performance grouts.
Development of standards and test procedures for high performance concrete.

As part of the Canadian Institute of Public Real Estate Companies (CIPREC) study on parking garage deterioration and repair, a study of the field performance of repair materials is being carried out together with the evaluation of sealers and membranes. Also being carried out at the National Research Council's Institute for Research in Construction (IRC) is a four year programme to select and evaluate repair materials. These programmes are funded for a total in excess of one million dollars. Complimentary to the SHRP programme, the C-SHRP programme covers the investigation of the field performance of shotcrete and is current.

A previous major study "To Quantify The Service Life Of Existing Canadian Methods Of Rehabilitating Concrete Decks, Beams, Piers and Abutments" was terminated after the first year. A modified programme concentrating on the performance of overlays has now been initiated.

Ontario Hydro has long carried out research into concrete technology and many hundreds of reports are on file at their Kipling Laboratories, and available if required. The main areas researched that would be of ongoing interest to a Ministry programme of R&D are in the following fields:

Thermal effects of hydration -
measurement, control and construction measures.

Repair materials evaluation.

Improvement of grouts.

5.3/France

A major research programme is the Projet National "Voies Nouvelles Des Materiau Beton" (VNB) - New Ways For Concrete. This programme is a collaboration between contractors, suppliers, owners and laboratories.

It appears that the emphasis is on high performance concrete rather than high strength concrete, although the pilot project for the application of the programmes technology was a bridge using 60 MPa concrete[38]. A consistent high modulus concrete was made and placed at 20-25 cm slump. The high strength was achieved without the use of silica fume.

Of interest was the use of an AMS type test procedure to calibrate the thermal characteristics of the mix so that predictions of heat problems in the structure could be made. Also of interest was the emphasis on a high quality finish as struck.

It was stated that bridges will be a major application for high performance concrete in France.

5.4/United Kingdom

At the September 1990 Dundee conference on The Protection of Concrete the Minister responsible for Roads and Traffic stated that 700 km of concrete pavement had been constructed in the last ten years, or about 20% of all roads. PCC is an alternative on all contracts. The UK budget for all road construction in this decade is about $25 billion CDN.

Research funding has however been small, and efforts are under way to increase industry participation. To this end the UK Department of Transport and Scientific and Engineering Research Council have approved a five year $12 million CDN programme for projects funded 50/50 with industry.

In a recent paper Brown[39] reported on a study of the in place quality of bridge concrete. Attempts to correlate properties relevant to durability were complicated by high scatter and a lack of critical data on the early age environment to which the concretes were subjected. The need for basic laboratory studies to identify durability mechanisms was emphasized.

5.5/Norway

Norway is one of the leading countries in the development and use of high performance concrete. A number of major research projects have been carried out or are currently under way[40]:

1983 - 1986	Design and Structural Utilization of High Strength Concrete
1986 - 1988	Phase 1
1989 - 1990	Phase 2 Structural High Strength Concrete
1987 - 1991	Material Development High Strength Concrete
1989 - 1991	Light Weight Aggregate Concrete For Floaters

Total annual budgets for these projects is 3 to 3.5 million dollars. The projects are a cooperative effort between the Royal Norwegian Council For Scientific and Industrial Research (NTNF) and industry. Industry is the main contributor. The predominant use of high performance concrete is in offshore structures for the oil industry and in transportation. Transportation uses include highway bridges, tunnels, floating highways and tunnels, and high strength pavements including high strength concrete repairs and overlays. High strength pavements are seen as an alternative to asphalt. Materials developments include the use of shotcrete with silica fume and steel fibres, a two point workability test, and a device which measures the density and internal friction of fresh concrete during the compaction process. These two tests are directed at improving the compactability of mixes over a range of slumps from zero to 240 mm. The achievement of strength and durability is being sought by:

> The reduction of maximum water - cement ratio in bridge decks to 0.40 in very aggressive environments.

The use of silica fume to improve concrete quality.

Increase of minimum cover to reinforcement.

Crack or stress control near exposed surfaces.

Improvements of curing conditions.

Control of curing temperatures and temperature differentials.

One of the most interesting developments in quality control is the Curing Technology system developed in Denmark described elsewhere in this report. This system is being applied by contractors to monitor strength development in place, predict heat development and gradients, design protective formwork and insulation and control its application and removal to optimize strength development and reduce excessive thermal gradients and cracking.

An interesting aspect of the Norwegian construction industry is the high level of quality control exercised by contractors of their own volition. Granted that an offshore platform like Gullfaks C could not be built without a high degree of quality control, nevertheless, it is evident in meetings and site visits that quality control is seen as the key to economic and reliable production of high performance concrete. Contractors sponsor and embrace the latest technology, seeing it as beneficial and part of their role. Gullfaks C incorporated one slipform operation which placed 114,000 m^3 of concrete and achieved a mean 28 day strength of 79 MPa and a standard deviation of 3.4 MPa. To date 70 km of high strength pavement have been placed. Details of mix designs are given as follows[23].

	MIX I	MIX II
Portland Cement 'P-30-4a	395	450
Silica Fume	20	75
Plasticizer	2	8
Superplasticizer	6	20 - 25
Sand 0/8	913	830
Crushed stone 6/16		900
Crushed stone 6/22	1000	
w/(c + s)	0.37	0.22 - 0.24
Slump in cm	2 - 3	10
Mean Strength at 28 days (cubes)	97 N/mm^2	135 N/mm^2

Concurrent with the high strength pavement programme have been abrasion tests to quantify the relative abrasion resistance of high strength concrete and other materials.

5.6/EEC.

The BRITE projects fund concrete research in the EEC countries. The latest major award is for $5 million CND over three years starting in 1990, and involves a consortium of four countries. The primary areas are as follows:

France: New ways of mixing.

Spain: Chloride corrosion limits.

Germany: Expert systems.

Denmark:

a) Idorn: Mathematical models of systems to prevent ASR.

b) AEC: Early age properties and calculations of early age stresses from maturity.

5.7/Denmark

Denmark has long-been a source of state-of-the-art research and practice in the field of concrete technology. A current research project funded for three years for $2 million CND covers the following areas:

1. Freeze thaw resistance.
2. Chloride penetration.
3. Early age properties.
4. Fracture mechanics.
5. Multi-axial properties.
6. Fatigue.
7. Properties of cracked concrete.
8. Properties of high strength pre-cast concrete.
9. Effects of cover.
10. New materials for prestressed concrete.

Of particular interest is the Storebaelt (Great Belt) project. This comprises the crossing of an 14 km channel by a low level combined road rail bridge, plus a train tunnel and a high level suspension bridge for road traffic across the main navigation channel.

In these major transportation structures in a marine environment durability is to be achieved by the production of a highly impermeable surface layer of concrete (covercrete). The reinforcing steel is not coated.

The contract specification approaches the achievement of this objective in a number of ways:

Materials sources are designated, as are the properties of the materials.

Limits are set for all materials, with maximum and minimum limits for fly-ash and silica fume, and for the air content of entrained air (bubbles less than 0.35 mm).

Specific requirement are given for maximum temperatures, differentials within pours, and also between adjacent pours.

Cover limits are specified.

Curing is specified.

Extensive pre-testing is required, including large trial pours on site.

- The responsibility for quality control is completely the contractors.

Evaluation of the covercrete is by petrographic examination of cores and by in-place pullout tests. The concept of a strength test to assess relative durability is interesting. Strength is related to quality for each mix by trial, and limits for acceptable quality set based on these trials. All test ages are given in terms of standard maturity hours or days.

The use of this specification has led to the extensive use by the contractor of a number of innovative procedures.

All mixes are evaluated by an AMS procedure, and the data stored for use during production pours. All pours are instrumented by a temperature monitoring system. In a 100m x 25m post-tensioned girder 166 thermocouples are monitored for maturity and for temperature differentials.

Two in-place test methods are used for pullout strength. All testing technicians are required to undergo training by the developer of these tests systems, and diplomas are awarded.

Because the specification criteria for the properties of fresh and hardened concrete are difficult to achieve, and because mix development based on the testing of mature concrete would slow the contract schedule, early age testing is done of inplace strength and maturity relationships used for long term prediction. Additionally, and perhaps more importantly, the Dansk Beton Technik (DBT) Air Void Analyzer is used to check the air void system of the fresh concrete. The routine use of this equipment was witnessed on two consecutive days and it was seen to be

quick and simple to use. Generally about 15 to 25 minutes elapse from sampling fresh concrete to a complete print out of the test data. Samples can be taken from tests samples or, alternatively, from freshly compacted concrete in the forms. The computer and printer supplied with the test equipment (which is in itself compact) is contained in a standard briefcase. A copy of a typical test print out is attached as Appendix 4. The advent of such test equipment makes practicable a performance specification for the quality of the air void system in place.

All site staff have also attended lectures by Irvin Poulsen, who was involved in the conceptual and detailed preparation of the contract specifications and others, so that the specification intents and background are understood. All technicians in Denmark authorized to measure the air void system in hardened concrete have been trained by the same agency to ensure low inter-laboratory variation in test results.

5.8/Japan

Main directions of concrete research in Japan are flowability of concrete mixes, high durability concrete, anti-washout concrete, inverted construction method and building construction using high strength and high quality concrete and reinforcing steel. Nojira et al summarize the work at the Kajima Institute of Construction Technology as follows[41]:

> "Efforts are underway to better understand concrete flow and segregation and applying principles from diverse fields as fluid mechanics and rheology to develop rational methods for mix-design and produce other special concretes. It is hoped that these results would help in the development of "self-placing" concrete and lead to accelerated construction methods."
>
> "Also, in recent years, durability of concrete on account of alkali-aggregate reaction and reinforcement corrosion, has attracted global attention. Because of the limited availability of good quality aggregate and the island nature of the country, both these problems have also been a focus for research in Japan. Several methods, including development of new materials use of different types of formworks in construction, etc., are being considered to achieve quality and high-durability concrete construction."

The philosophy being followed here with regard to concrete that is virtually self-placing and yet experiences no slump loss or segregation is interesting. Ideally it is Kunishima's "dreamful" concrete. Modified superplasticizers with slump retention to at least 2 hours plus cellulose based derivatives are used to achieve the desired rheology. Such concretes, often termed anti-washout concretes, are suitable for both above and below water uses. While significant progress has been made by Kunishima and Nojira et al it is recognized that further refinement of mix design procedures is required. It is anticipated that mix design procedures will have to be compatible

with the future use of robots in the construction industry coupled with a high standard of quality assurance.

Durability improvements are sought by classic methods, and also by the use of admixtures such as glycol-ether and amino alcohol derivatives combined with the use of supplementary cementing materials.

In the construction practice field special form liners are used of water absorbing textiles and permeable sheet materials to reduce the water content of the near surface layer and improve its quality.

Efforts to produce durable repair materials are considered to have had limited success to date, and research continues.

In the New RC programme for building structures, running from 1988 to 1992, a large number of research projects cover materials, rebar performance, structural performance and structural design[42]. Funding is $7.4 million over 5 years with industry contributing two thirds of the money. In 1989 in the materials field alone some 13 projects were carried out or started as follows:

"Researches on Concrete

a) Quality examination of cement for high strength and super high strength concrete

b) Quality examination of the aggregate for high strength and super high strength concrete

c) Quality standard and application criteria of the admixture for high strength and super high strength concrete

d) Development of the binder for high strength and super high strength concrete

e) Design method of mix proportion for high strength and super high strength concrete

f) Evaluation method of workability of high strength and super high strength concrete

g) Evaluation of mechanical properties of high strength and super high strength concrete

h) Evaluation of long-term properties of high strength and super high strength concrete

i) Evaluation of compressive strength of concrete in structures

j) Evaluation of durability of high strength and super high strength concrete

k) Development of essential construction techniques for high strength and super high strength concrete

l) Evaluation of fire resistance of high strength and super high strength concrete

m) Evaluation method of quality reliability of strength concrete in structures"

The large numbers of papers quoted in some of the above exotic areas are impressive evidence of the activity current in Japan.

5.9/U.S.A.

Highway research and development programmes are coordinated and administered nationally by the 3,400 employee Federal Highway Administration (FHWA) of the U.S. Department of Transportation (USDOT). Within the FHWA, The Office of Engineering and Highway Operations Research and Development is the umbrella department for these activities. While the FHWA is only directly involved with 22% of the 4 million miles of US roads, they account for more than 79% of the total vehicle miles travelled. The Office of Engineering, under the direction of Mr. T. Pasko, has three divisions: structures, pavements and materials. It operates the FHWA laboratories at the Turner-Fairbank Highway Research Centre at McLean Virginia near Washington. Input to highways research is provided by the Steering Committee On Research And Development Needs In Highway Construction Engineering Management, a committee of the Transportation Research Board (TRB) which in turn is part of the National Research Council. In its latest report this committee received 72 research and development needs, and identified 16 as being significant. Those of interest in this study are as follows[43]:

HIGHEST PRIORITY RESEARCH AND DEVELOPMENT NEEDS.

PRIORITY	PROBLEM	PROBLEM TITLE	COST	TIME (MAN YEARS)
1	QA-1	Performance-Based Specifications for Highway Construction	$27,000,000	180
3	QA-4	Development of More Effective Rapid Test Methods and Procedures	$ 9,000,000	60
4	PC-12	Constructability Review	$ 450,000	3
5	C-16	Improving the Quality of Work on Highway Projects	$ 450,000	3
7	QA-2	Responsibilities for Quality Management	$ 3,300,000	22
12	ET-2	Certification Programs for Construction Engineering Technicians	$ 300,000	2
16	PC-7	Optimizing the Use of Consultant Versus In-House Staff for the Design and Construction of Public Works.	$ 225,000	1.5

TOTAL COST ESTIMATE: $45,225,000 (for all 16 projects)

with the future use of robots in the construction industry coupled with a high standard of quality assurance.

Durability improvements are sought by classic methods, and also by the use of admixtures such as glycol-ether and amino alcohol derivatives combined with the use of supplementary cementing materials.

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12	ET-2	Certification Programs for Construction Engineering Technicians	$ 300,000	2
16	PC-7	Optimizing the Use of Consultant Versus In-House Staff for the Design and Construction of Public Works.	$ 225,000	1.5
		TOTAL COST ESTIMATE:	$43,225,000 (for all 16 projects)	

Overall, the USDOT administers the Nationally Coordinated Program (NCP) of Highway Research Development and Technology. This programme identifies priority research programmes, and helps to avoid duplication to maximize the use of resources. It also participates in other research programmes such as Highway Planning and Research (HP&R), National Cooperative Highway Research Programme (NCHRP), FHWA and the Strategic Highway Research Programme (SHRP). In 1986 1209 R&D projects were in progress under the above agencies excluding the SHRP programme which had not been started[44]. In 1988 the HPR programme covered 150 active research projects, with total funding over $15 million[45]. Of this total, Texas had 93 of the contracts for a total value of nearly $10 million.

Clearly there is a large volume of research current or recent, and many projects have relevance to Ontario problems.

Two devices for use on slipform pavers which were brought to an advanced stage of development by FHWA but not proceeded with are of potential interest in an expanded Ontario paving programme. The first monitors the developing density of fresh concrete and can thus monitor effective and continuing compaction and give warning of any malfunction of vibrators. The second is a smoothness measurement device to give instant evaluation of surface finish.

The current projects most significant to this report are the six SHRP contracts on concrete research.

The relevance of the SHRP projects to the proposed research plan can be summarised as follows:

General.

All main SHRP contracts start with an extensive review of literature and current practice. They are, therefore, of themselves a good source of state-of-the-art data evaluated in the context of North American practice. As this is the first activity in SHRP contracts all such reviews are available now. An example is the annotated bibliography on High Performance Concretes compiled by C205 contractors. This contains 830 references.

In the following text S7/2, S8/1 etc refer to projects recommended in the research plan. See Tables 1-6 for details.

C201 Concrete Microstructure. Completion Date: Mid 1991.

The results of this contract will be relevant to the improvement of cover concrete if project S5/2 shows higher quality to be necessary. Guidance would also be available for projects S8/1 and

S8/2. Results of C201 relevant to S9/1 may also be available by the end of 1990 and this should be investigated by the researcher for S9/1.

C202 Eliminating or Minimizing Alkali-Silica Reactivity. Completion Date: Late 1993.

It is considered that the Ministry both has the solution of this problem well in hand and is aware of progress on C202. If project S5/2 shows a need to improve the quality of cover concrete, then the results of this study will be relevant to the use of larger percentages of SCMs.

C203 Resistance of Concrete to Freezing and Thawing. Completion Date: Spring 1993.

If project S5/2 shows a need to improve the quality of cover concrete the results of this study will be relevant.

C204 Non Destructive Testing for Quality Control/Condition Analysis of Concrete. Terminated: Spring 1991

Some useful work has been completed in the field of air void determinations on fresh concrete. Project S7/5 could therefore take advantage of this work plus the associated developments in SHRP IDEA programme 007 Quantitative And Rapid Measurement Of Air Void Systems In Fresh Concrete Used For Pavement And Bridge Structures, and 011 Insitu Determination Of Entrained Air In Freshly Mixed Concrete Using Fiber Optics - A Nondestructive Approach. In addition, the DBT Air Void Analyser developed in Denmark should be tried. At this time it is thought that the simple procedures partially developed in C204 and the DBT Air Void Analyser are the most promising. Recent comparative trials in Minnesota may prove to be inconclusive as an overall measure of the comparative and absolute merits of all these test methods.

The non-destructive in-place strength tests evaluated in C204 could also be incorporated in the S5/1 and S5/2 projects on the same basis as the use of these tests on the Storebealt project.

Other QC/QA tests partially developed under C204 would be available now and could be considered for incorporation in procedures specified in performance specifications if this seems beneficial.

C205 Properties Of High Performance Concretes. Completion Date: March 1993.

If project S5/2 shows a need to improve the quality of cover concrete the results of this study will be relevant. For projects P1 to P4 the results of C205 to date should be reviewed for assistance.

C206 Optimization Of Highway Concrete Technology. Completion Date: March 1993.

This project reviews the findings of C201 to C205 and sythesises them into specifications and expert systems. The results of this project should be reviewed by the project TT2b committee in the light of the results of projects carried out in this Directions In Concrete Research programme. This will help to refine and, where necessary, to re-direct this plan.

Of the Structures contracts the following will have results useful to this plan.

C103. Concrete Bridge Protection and Rehabilitation: Chemical And Physical Techniques. Completion Date: March 1993.

The results to date on this contract would be relevant to projects S8 and P1.

In May 1990 NIST held a three day workshop to develop a research programme for high performance concrete in the U.S.A. An outline of research needs was developed in five major technical areas. Recommendations include:

Materials and Proportioning.

Development of improved proportioning methods with statistical procedures to optimise mix programmes. Develop methods of testing fresh and newly hardened concrete.

Processing and Curing.

Characterise rheology, mechanical properties, durability, and ease of placement. Investigate effect of mixers. Evaluate all heat and moisture factors in achieving optimum curing.

Mechanical Properties and Test Methods.

Improve testing machines and procedures. Achieve better measurement and understanding of in-place strength, and of other mechanical properties. Establish expected mechancial properties of local materials.

Durability and Test Methods.

Develop durability and performance criteria for HPC including predictive tests for freeze-thaw resistance and permeability, and service life prediction models.

Structural Performance and Design.

More data is needed on all mechanical properties. Constructability issues included control of cracking.

Standards and Acceptance Criteria.

Develop performance standards with appropriate acceptance and uniformity requirements. Introduce appropriate tests and procedures to confirm compliance.

Institutional Barriers.

Barriers to the development of new technology and the wider implementation of developed technology need to be breached. Improvements in information transfer, product approval and bid systems are key elements. New technology needs to be marketed effectively.

Another network of research centres forms the Centre For Science And Technology Of Advanced Cement Based Materials (ACBM). This network is comprised of Northwestern, Illinois, Purdue and Michigan Universities plus NIST, and will be funded for at least five years. The research will enhance the understanding of the fundamental principles and properties of ACBM's, develop models and transfer technology to the construction industry.

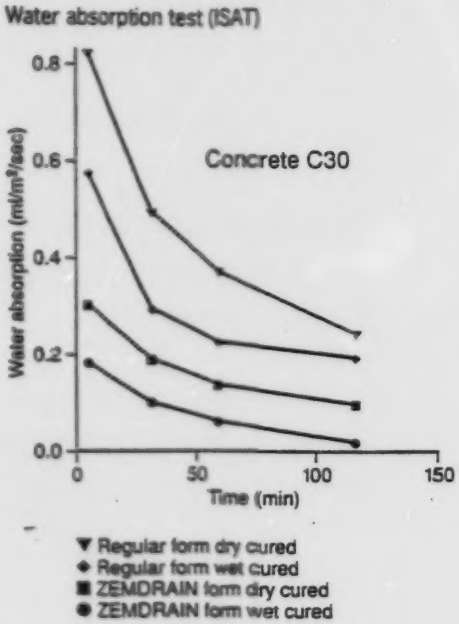
5.10/Germany

As in Japan water absorbing textiles are being used to improve the quality and appearance of the near surface layer of the concrete. One product ZEMDRAIN is marketed by DU PONT.

Performance data shown in the following table and figure from the manufacturer's brochure.

Building site tests with Zemdrain and Plywood Board

CONCRETE C30		PLYWOOD	ZEMDRAIN
Surface harness (DIN 1040)		35-36	46-48
Surface Tensile Force (N/mm^2)		1.9	3.3
Carbonation Penetration (mm)			
(a) common air	126 days exp	3.8	0.6
	180 days exp	5.3	1.0
(b) 3% CO_2 in air	126 days exp	4.4	2.0
(65% RH)	180 days exp	6.5	3.6
Frost Resistance Austrian B3033			
(a) loosened material (g/m^2/5 cycles)		10.08	1.2
(b) dynamic modulus (% retained)		57-63	>100
Chloride Penetration depth (mm)		15-20	3.11
Surface Abrasion (thickness loss (mm))			
(DIN 52108)	after 88 cycles	1.54	1.17
	after 176 cycles	1.36	0.84
	after 264 cycles	1.11	0.77
	after 352 cycles	1.07	0.71



5.11/Switzerland

Having established a relationship between durability (evaluated as freeze thaw resistance) and a morphological examination of thin sections of small diameter cores this technique has been used to evaluate pavement and structure concrete. The cores are drilled at one or two days of age and examination and evaluation is said to be rapid[46,47].

6/Discussion

6.1/Design and Constructability

The concerns of the design office centre on three areas.

Firstly, it is felt that there is a need for a policy on the use of sealers with reliable service life data for each type and use.

Secondly, there is a major need for reliable data on the selection and service life of repair materials and systems. This data is vital to the establishment of a long range bridge management programme.

Thirdly, there is concern about major cracks appearing on large bridge deck pours.

It must be true that the simpler it is to build any given structure the higher are the chances of doing it successfully as are the chances of doing it more economically. Constructability has for some time been a major concern of the American Concrete Institute. In the FHWA/TRB report "Research And Development Program For Highway Construction Engineering Management"[43] constructability is listed as a priority amongst the top 17 priority programmes recommended for funding, and $450 thousand is budgeted.

6.2/Specifications

Specifications not only lay down requirements for materials and practice but also reflect the philosophy of the specifying agency. To date MTO concrete specifications have been primarily prescriptive documents with a recent minor change into a very limited performance approach based on compressive strength as the only performance criterion. Historically the majority of specifications for concrete written by public and private agencies have been prescription specifications with sometimes a few criteria for performance. In the past where true performance specifications have been used, often in design build and fast track contracts, the intent of the specifications have been to a large extent circumvented with unsatisfactory results for the purchaser.

A good example of a major agency currently wedded to the prescription approach of many years is the New York Department of Transportation. Prescription specifications are seen as creating a level playing field over a large state for the many bidders involved. Additionally it is felt that the very extensive knowledge of concrete materials and mixes gained by the Department over many years makes the agency staff best able to judge what is the best

concrete for each project. Bidders therefore compete on a cost basis with a minimum cement content and fresh concrete properties specified. Aggregate, cement and admixture testing, and the determination of mix designs is done by the Department staff, who also do the concrete inspection and testing including batch plant inspection.

As for many agencies, recent cost cutting measures have led to reductions in agency staff and the use of contractor inspectors and technicians provided by consultants. For technicians an ACI Field Technician qualification is specified, but there are no similar certifications available for batch plant inspectors. Such staff are sometimes considered to be "warm bodies".

When this agency becomes interested in new materials or processes, the central materials organization makes laboratory and field evaluations to determine whether to proceed or not. A recent trial was made of a silica fume overlay for a deteriorated bridge deck.

While it would appear that this agency feels it has good control of the quality of the concrete it purchases, it would appear that in some fields it is, like the MTO, not adopting new materials quickly.

The prime arguments for the use of performance specifications are that they encourage the use of innovations, and can result in economies.

In the May 1990 issue of the Strategic Highway Research Program newsletter Focus, Roger L. Yarbrough in an article entitled "In Search of Performance Excellence"[48] pointed out:

> "The deficiencies in method specifications are so restrictively detailed that a contractor has very little flexibility to make decisions or to change or alter anything about the process....Consequently, contractors have little incentive to be innovative or improve quality."

He envisaged a step by step conversion from method specifications to true performance specifications.

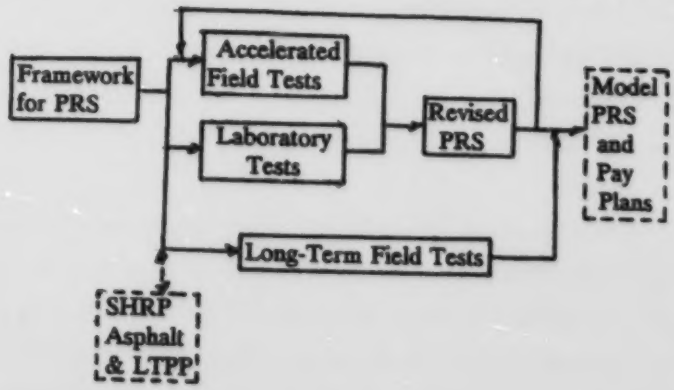
> "We also must have better contractural incentives to get high quality work done by contractors....One way to do this would be to award contracts using quality assurance/quality control (QA/QC) specifications."

Certainly the QA/QC approach seems a likely candidate for the next generation of MTO specifications but only if meaningful new accelerated performance-related tests and mix design procedures can be developed that relate closely to performance characteristics. Then quality assurance specifications will gain much quicker and wider acceptance and use.

The crux of this argument is the need for rapid and reliable ways of determining if the end product delivered will meet performance requirements. In construction this cannot mean waiting until a bridge or a section of pavement is completed. Implied is a need to determine by tests on the fresh concrete and on the hardened concrete very early in its life that the finished structure will provide the service life and performance requirements contracted for. For a structural concrete this could mean determining compliance by testing say 24 hour concrete. These tests would be made on a mixture potentially made of more than one cementitious material, more than one chemical admixture, subjected to different and fluctuating temperature and moisture conditions at a time when hydration processes are changing the microstructure of the concrete being tested. Allowing for these factors, and the inherent variation of all the materials themselves, presents a formidable challenge to the requirements for testing.

There is an extensive consensus that progress can best be made by developing performance specifications. The 1990 FHWA/TRB report "Research and Development Program for Highway Construction Engineering Management"[43] identified "performance-based specifications for highway construction" as priority number one. This research need was estimated to cost $27 million and take 180 man years of effort! A FHWA hosted meeting in Washington on July 17th, 1990 decided to allocate each of the 10 materials in construction areas to appropriate TRB committees. These committees are to be asked to develop a series of research needs statements and statements of work for research studies. By this next step it is hoped to achieve a research program and implementation plan for each of the 10 areas. Two sample problem statements were provided for guidance[49]. One was for PCC pavements and envisaged a budget of $4.5 million and 30 man years of effort.

FHWA staff have, since 1988, carried out work on the development of performance related specifications (PRS) for asphalt and PCC pavements under High Priority National Program Area (HPNPA) programs[50]. Their conceptual approach can be shown on the following figure:



Research approach for developing PRS

FHWA Report FD-89-211 of September 1989, Development of Performance-Related Specifications for PCC Pavement Construction reviewed work to date in this area, and made recommendations for further study[51]. It has become recognized that control should be concentrated on those factors in materials and construction that have the most effect on final performance. Once verified, these factors can be incorporated in a performance specifications that rewards contractors for producing a structure or pavement that performs better than specified minimums, and provides for penalties for inferior performance. In a pavement factors affecting the performance are air void system, strength, thickness and riding quality. Pennsylvania's Department of Transport has made a significant step towards this with a Restricted Performance Specification (RPS) for concrete pavements[52]. Payments based on lots of 5600 square yards of pavement and a weighted formula takes air content, compressive strength, thickness and surface quality determined by the California profilograph into account. With regard to surface finish requirements these were the subject of a dialogue between the DOT and the contracting industry. Initially a requirement of 40 inches per mile was accepted on the understanding that the limits would be tightened year by year until a surface entirely acceptable to the public was obtained. Today the limit is 10 inches per mile, higher-values attracting a penalty and values under 7 inches qualifying for a bonus.

6.3/Supervision

There are several areas of concern. The number of QA staff is very small. Their depth of knowledge on concrete technology needs improving, not just to meet the present contract QA needs, but especially to enforce future increases in performance requirements. The inadequate level of staffing is exacerbated by the increasing size of the highway programme. Site staff also need significant improvements in knowledge to apply QA procedures on a day by day basis.

Criteria for consultant staff need better definition. Apart from competence, staff need to be dedicated to a project. Conversely, consultants need to see an ongoing volume of work in order to properly staff highway projects.

6.4/Testing

The fundamental flaw in the present round-robin system is that the testing is not blind. The testing laboratories know that the test cylinders are from the Ministry as part of this approval system. Despite this, a small number of laboratories fail to produce satisfactory results. The Ready Mixed Concrete Association of Ontario has for several years conducted their own blind testing programme, sending test cylinders to commercial testing laboratories without identifying their purpose. The test results obtained by the RMCAO have not been reassuring,

both the standard deviation and coefficient of variation being significantly higher than those obtained in MTO tests. It is considered, that this is the only valid way to conduct such testing, and a change to this procedure by the Ministry should be considered.

The regional contracts for laboratory testing are let by the Ministry on the basis of price. Competition is keen. There is a perceived cachet in having the contract. Having it can also be perceived as having a technical benefit in helping to obtain the field testing on MTO performance contracts. In Central Region in 1990 the successful bidder won by reducing the successful 1989 price by two cents a cylinder to $3.98. This price was appropriate for a competent private laboratory about 1970!

In bidding for a contractor's testing on a major interchange contract in 1990 the same testing laboratory, determined to get the testing contract, made a careful analysis of the project needs, and cutting costs and profit margins to the bone offered the contractor a price of $120 thousand since only a firm price was acceptable. All risks for overtime and extra work had to be assumed by the testing laboratory. The contractor, already having obtained other prices, indicated that the winning price would have to be $78 thousand or less.

In England in the early 60's a study was made on a major expressway contract to determine appropriate levels of quality control testing and the costs involved[53,54]. This survey led to the determination of the budgets that should be allowed for such testing by the U.K. Ministry of Transport. Subsequently an agreement was drafted to provide for quality control on all expressway contracts by independent testing laboratories, and compensation rates agreed which were commensurate with the provision of professionally competent levels of testing and inspection. The budget levels determined by the British study would have provided of the order of $200 thousand (in the range of $175 thousand - $225 thousand) for the concrete testing on the MTO contract discussed above. Paying $200 thousand for $200 thousand worth of testing does not guarantee to the Ministry that the testing will be done properly. Paying $78 thousand for $200 thousand of testing will probably guarantee that it is not.

There are a number of aspects of concrete testing that bear consideration. Concrete testing cannot be automated like the manufacture of widgets. There are no legal ways to improve efficiency or productivity. If testing is to be meaningful all sampling and testing procedures must be followed to the letter. They aren't. Figure no. 4 shows concrete test cylinders on a Ministry performance specification contract standing in the sun on a hot sunny day. Granted

some attempt has been made to shield them from the sun and retain moisture, but to no avail. Close by were the compressive cylinders made by the representative of the concrete supplier.

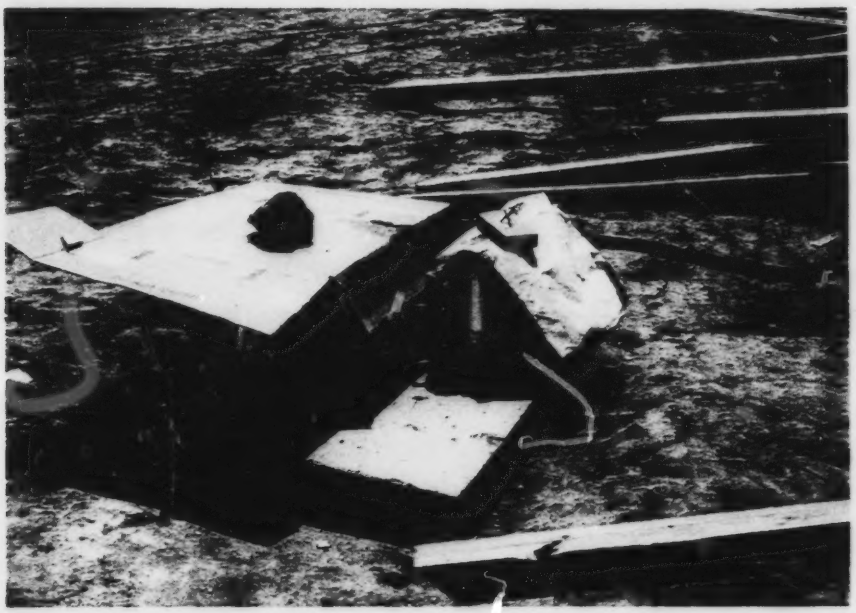


Figure no. 4. Test cylinders in the sun.

One has to be concerned about the level of knowledge of Ministry site staff in failing to see the deficiencies exhibited by this example of testing.

Historically the commercial concrete testing industry has not been perceived as operating at an acceptably high level of reliability. The multiplicity of relatively small sized companies has produced an industry too fragile to maintain adequate prices, and thus vulnerable to the almost universal construction industry policy of awarding testing contracts on a low bid basis. Furthermore there has been no perception by the structural engineering fraternity or indeed by the Construction Industry that concrete testing is a function that should be adequately funded if there is to be any real expectation that procedures will be followed conscientiously. The feeling has been that to a large extent concrete test cylinders are not that critical. Actual structural failures have been few, and low test cylinders are usually found to be the result of deviations from correct sampling, curing and test procedures. Otherwise, on further investigation, in-place strengths are either found to be in accordance with design or, if marginally low, acceptable with or without some additional curing.

Current trends will change and indeed will have to change this situation. In the private field the increasing use of high performance and high strength concretes has underlined the need for meaningful testing. Concrete mixes are more complex, ingredients highly susceptible to variations in handling and deviations from standard test procedures can produce test results that fall far below design requirements. The financial implications on large projects with accelerated and rapid construction schedules can be horrendously expensive. Stoppages to investigate apparent strength problems are almost unacceptable, and QC and QA provisions must therefore provide the correct end product data. It is interesting to note that on very high strength concrete projects, the whole project team will now support the employment of a high priced, competent testing laboratory with a proven track record of reliability. As the trend to true performance specifications proceeds, and as more and more exotic materials and mixtures are used, the need for valid and rapid data will bring in the use of more sophisticated test procedures. Earlier determinations of the acceptability of concrete will be used, and the need to act on this data will be at a time when generally no defects in the quality of the concrete will be apparent. Brave indeed he who rejects a bridge pour, or stops further construction on the basis of a $4.00 cylinder test or its equivalent.

More meaningful test procedures will need to be adopted. Ministry staff will need the appropriate training, and the compensation and performance of testing laboratories will both need to be optimized. Consultants will need to dedicate trained staff to projects.

The Ministry has no inherent or intrinsic interest in concrete test cylinders. The Ministry is only interested in the quality of concrete in its structures. It must move from funding the QC of the suppliers to funding the QA that guarantees the end product.

6.5/Paving

With the currently favourably economics of concrete pavements, their lack of rutting, and potentially long life - low maintenance characteristics, there is reason to optimize Ministry practice.

The approach used in Pennsylvania has been mentioned in 6.2. While riding quality is measured by the Ministry it is not a contract acceptance criterion, but should be. Observations on Highway 115 suggest that the road building industry can produce an acceptable quality of pavement. Improvements need to be made in finishing, tineing and the application of membrane curing liquids. It is not acceptable that each contract should start with sections of unacceptable quality. Clearly the industry needs a continuing volume of such work so that experienced operators can be retained for all critical operations.

Developments elsewhere suggest a number of potentially worthwhile areas to be explored. Missouri has recently overlaid an old pavement with a fast-track concrete overlay[35]. Norway has pioneered high strength concrete pavements and overlays (see 5.5). Latex modified overlays for bridge deck resurfacing could beneficially be replaced by silica fume concretes. Costs should be cheaper and chloride impermeability and resistivity better. MTO have already successfully placed one overlay on highway 126. The success here and increasing activity elsewhere predicates an increasing use of this technique.

It has been suggested that the Ministry should carry out trials to promote roller compacted concrete for highways, if only to facilitate its use on logging roads and other non Ministry roads. The base material covered by OPSS 315 is, of course, roller compacted concrete. Its use for pavements is questionable. There is a three year programme in this area currently being carried out in Quebec. Initial results are not particularly convincing, and probably the best policy in this area is to monitor that programme.

In the Highway 115 contract an asphalt bound open graded drainage layer (OGDL) underlies the concrete pavement. An ideal cement bound material for this purpose would be No-Fines concrete. Samples subjected to twenty years of severe exposure have suffered no damage, and it is an ideal drainage medium.

6.6/Materials

The vertical integration of concrete materials and supply companies, and the extensive foreign ownership of these companies is seen to decrease the responsiveness of the supply industry to MTO needs. It is in the long range interests of both to produce durable, serviceable concrete with the optimum life-cycle cost. It is to be hoped that the extended dialogue recommended in this report will help to achieve unity in progressing towards these common goals.

While supplementary cementing materials are increasingly seen as normal ingredients in high performance concrete the appropriate time for their wider adoption in larger cement replacement percentages may be in the near future, depending on further evidence of their durability performance.

Recent developments in admixtures are of great interest to the MTO. It seems possible that consistently acceptable air void systems can be achieved, and this critically important aspect of durability should be resolved. Other admixtures to improve cohesiveness, workability, and

surface appearance are of great interest. Of importance is a better understanding of cement-admixture-mixing water chemical interaction so that field performance is predictable and consistent.

Little needs to be done in the Ministry's control of aggregate quality other than complete the strategy for control of AAR.

The impetus for any changes in reinforcement specifications will need to come from the design office. Meanwhile some extension in the use of coated steel would be beneficial as would be standardization of detailing.

The overriding concern with concrete is its durability. The quality specified in OPSS 1350 meets the currently accepted criteria for good practice. The actual quality in-situ is not known, and determining this is a high priority need. Any need to improve this quality has to be shown by evaluating the adequacy of the present end product.

Shotcrete and grout are two important materials that need further development of materials, plant, and QC. Both materials have traditionally been produced in a very low tech manner not conducive to the consistent achievement of high quality.

The quality of formwork is a basic determinant of the quality of concrete. Improvements in durability and aesthetic quality can be achieved by modest expenditures.

The choice of repair materials and systems is a difficult one. Definitive guidance is lacking but much activity is current in this field. While working on the most urgently needed early strength materials the monitoring of activity by other agencies is the most cost-effective MTO approach now.

6.7/Current International Practice and Research

There are a number of common themes recurrent in the large body of research underway or planned. In the materials field, durability is the overriding concern. Research on this aspect is in a number of areas:

The fundamental principles effecting the rheology of cementitious systems.

The influence of cement, supplementary cementitious materials and admixtures, their interaction and optimum use.

The effect of temperature and moisture curing cycle parameters on the quality of the resultant microstructure of the usually multi-cement multi-admixture concrete mixture.

The development of laboratory and field test procedures to evaluate the concrete quality, particularly at early ages. In this connection the development of advanced maturity systems is a key to determining the heat characteristics or signature of a concrete mixture, and to monitoring specified and actual curing cycles, temperature gradients and in-place maturity. They should be commonly used as a standard procedure in concrete research programmes and consequently are proposed for use in the programmes in this report.

The use of performance specifications is seen to be the way to allow innovation, and achieve high performance concrete.

7.0/The Challenges

7.1/Introduction

The biggest challenge is to select and implement those research initiatives which will best enable the research and development branch to contribute to the quality of our highway system at the optimum economic cost. The branch has some notable achievements to its credit, particularly in grappling with the de-icing salt induced corrosion problem and bringing it under control. It must now move on to optimize to the benefit of taxpayers the exploitation of current concrete technology.

7.2/High Performance Concrete (HPC)

The term high performance concrete is currently much in fashion, and a number of definitions are being floated around. It is suggested that all the concrete placed by MTO is high performance concrete, be it in pavements, traffic barriers or structures. It is all to some degree or other subjected to degradation from traffic, wetting and drying, freeze-thaw cycles, de-icing salts and a wide range of temperatures. The writer considers that a 30MPa bridge deck that last 40 years without significant maintenance is made of high performance concrete. It is perhaps constructive to examine our philosophy with regard to high performance concrete.

From May 16th to 18th an invited group of engineers and scientists met at a workshop in Gaithersburg Maryland to help the National Institute of Standards and Technology (NIST) formulate a research plan for the USA in the area of high performance concrete.

Some propositions proposed for consideration at the workshop were as follows:

1. All engineering concrete should be of top architectural quality - not only because it should look good but because uniformity in appearance comes from uniformity in composition and compaction, and no leakage at any joints. What needs to be done to achieve this?

2. We know how to make high performance concrete. Why do we so often fail to achieve it in the field? Are those who make concrete structures isolated from researchers and their findings? What use are academic laboratory achievements if they are not incorporated into practice?

3. The five phases that have to be executed correctly in order to achieve HPC are shown in Figure 4.

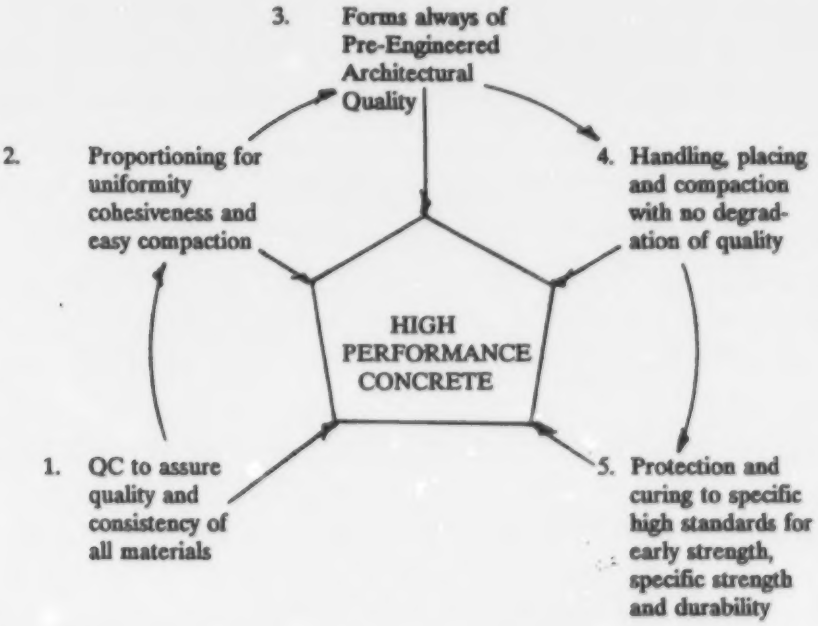

3. Forms always of Pre-Engineered Architectural Quality
2. Proportioning for uniformity cohesiveness and easy compaction
4. Handling, placing and compaction with no degrad-ation of quality
HIGH PERFORMANCE CONCRETE
1. QC to assure quality and consistency of all materials
5. Protection and curing to specific high standards for early strength, specific strength and durability

Figure 4: HOW DO WE ACHIEVE HIGH PERFORMANCE CONCRETE?

The aims expressed in item 1 will be fundamental to the aims of any research programme resulting from this study. The workshop held by NIST was extremely fruitful and a summary of some of the findings of this workshop have been reviewed in section 5.9 of this report.

There are perhaps three main conclusions that can be drawn from this workshop.

1. Progress can only occur if innovation is allowed, and the contractor can exercise to the full his expertise and that of his suppliers.

2. Such progress can only result from the use of performance specifications which place full and clear responsibility on the contractor.

3. Test procedures are needed so that the owner can determine very early in the life of the structure that the performance of the concrete will meet specific requirements.

It is germane to this project that a recurrent theme at the NIST and Berkeley meetings was the importance of information transfer. A large volume of research on concrete is current, funds are limited and only the poorest of researchers wishes to reinvent a series of wheels already invented by others.

At the Berkeley Symposium a meeting was held of a group which adopted the title "International Cooperation Group". Fifteen attendees from Canada, France, Japan, Norway and the USA met to discuss improvements in information transfer. A model was discussed and it was agreed that since the five countries have "National" research plans, details of these would be exchanged between the participants in the near future. In addition the interest of the group would be brought to the attention of relevant Comité Euro-International du Béton (CEB), Fédération Internationale de la Précontraite (FIP), International Union of Testing Laboratories for Materials and Structures (RILEM) and American Concrete Institute (ACI) committees as CEB/FIP represent about 50 countries, and are involved in the present production by the EEC of uniform European wide standards for cement, ready mixed concrete and concrete performance, production, placing, and compliance. This has since been done, and a representative committee proposed to implement this information exchange.

7.3/Discussion

There is a very large volume of research being carried out worldwide at the moment. Common themes run through all these programmes. The prime concern is for durability. Higher and higher strengths are being sought. Much effort is being put into studies of the fundamental mechanisms that affect the properties of fresh and newly hardened concrete. Test procedures that enable one to verify these properties quickly and reliably are being developed.

The MTO research budget is small. It is necessary to select programmes which solve specific problems of concern to MTO or which pave the way for future changes in MTO policy. It is vital that MTO monitor world research on an ongoing basis so that it can take advantage of discoveries of benefit to it, and where sensible, modify or change its proposed research programme to take into account developments which can be refined and applied to local practice. MTO staff have always been active in ACI, Transportation Research Board (TRB), American Society for Testing and Materials (ASTM), Canadian Standards Association (CSA) and other relevant bodies and monitor ongoing developments in concrete technology very well. It would be highly beneficial to extend this activity, improving and extending the monitoring and evaluation of research results worldwide. It would not be difficult to establish contact with the main centres of activity and produce an ongoing synthesis of material of specific interest to MTO.

It would also be beneficial for MTO to make maximum use of the knowledge of non-MTO persons active in the field of concrete technology. There are Academics, Consultants and persons in the contracting and supply industry who would have something to offer. Perhaps an annual one or two day workshop of a "Research Review Committee On Concrete Technology" could be held. Current developments could be reviewed against the current and planned R&D programmes and modifications and changes made where seen to be desirable. The out-of-pocket cost could probably be limited to the provision of a venue, travel and hospitality. Perhaps the activity could become part of the responsibility of the MTO Structures Durability Committee. An ongoing programme of research cannot rationally be designed or implemented without regard to Ministry policies and future intentions. The interaction between R&D, and developments in specifications and in construction practice is essential if the limited R&D budget is to be spent effectively.

The criteria for selection of consultants to carry out research and development programmes should be re-examined. Specific past experience in a subject should be a prime requisite, and opportunities to involve industry should be identified.

Surprisingly, field construction staff of the Ministry do not see any significant material problems. It is suggested here that current practice falls short of the intents embodied in contract documents and specifications.

There is a need to improve site practice based on existing standards before attempting to introduce new or more sophisticated procedures and materials to the field. The need is for more education, training, and information transfer to those charged with enforcing existing standards.

The case for performance specifications has been made in this report, and there is almost universal agreement that they are needed to ensure the proper adoption of technology and innovation. It is realized that this cannot be done overnight. Indeed a pure performance specification may never be realized, some prescriptive sections of necessity being retained. The process should nevertheless be started if the Ontario road construction industry is to mature. One negative impact of past policies is a construction industry with virtually no R&D or QC capability of its own. This is very different to other countries where Ministry and consultants' staff would be met in the field by highly competent QC staff of the contractor. A decision in principle must be made to move towards more extensive performance requirements in specifications. It is appreciated that many MTO contracts are executed in remote areas, and it may be that performance specifications ultimately developed may never be applied to all

contracts. At present some contracts are carried out with restricted performance specifications but most are not. The problems of achieving higher performance on some Ministry contracts should not inhibit progress for the majority. The MTO must also be firm about QA performance both inside the Ministry and by outside consultants. Round-robin testing must be blind testing if results are to be meaningful. There can be no valid objection to this by competent consultants.

Another ongoing consideration requiring policy consideration is research funding. The amount spent by the construction industry in Canada is pitiful. The funding available to MTO is inadequate. If, for example, the road programme not only expands but uses more PCC pavement many will benefit. It would therefore seem reasonable for Cement Manufacturers, Ready Mixed Concrete Suppliers, Admixture Suppliers and Road Contractors to contribute to a fund specifically for road research. Examples of R&D projects of prime interest to industry and suitable for joint funding would be:

- Scaling and freeze-thaw resistance of concretes containing large percentages of SCM's
- Development of improved salt scaling test for concrete, particularly those containing large percentages of SCM's.
- Development of optimum curing cycles for concretes containing large percentages of SCM's.
- Granite curbs.
- Improved grout mixers.
- Improved shotcrete plant.
- Development of pre-mixed grouts.
- Development of pre-mixed shotcrete.
- Development of pre-mixed repair materials.

This funding added to the Ministry funds would have a synergistic effect on the amount and pace of research. One problem faced by Universities is the lack of long term funding. A larger research funding would provide money for more research in Universities and elsewhere. It would be in the Provinces long range interest to help one or more Universities build up their physical plant for concrete technology research as has happened in Quebec.

In the pavement field an approach similar to that adopted in Pennsylvannia should be adopted. Some differences in criteria and weighting would be desirable. Initially, strength, air content, thickness and riding quality might be used. Later on, the quality of the air void system as placed and in the near surface layers would be included. For public acceptance riding quality

would be given a high weighting. Liaison should be set up with the road construction industry and their suppliers. On the understanding that the continued expansion of the use of concrete pavements will depend on their performance, a dialogue should be started. Realistic standards should be set now on the understanding that they will be tightened annually until the optimum product is attained.

8.0/Policy Options

The activities of the Research and Development Branch serve two main functions.

Firstly, research may be needed to solve existing problems. Two examples of this are the deterioration of concrete structures due to de-icing salt corrosion and to alkali-aggregate reactions. The Ministry has been a world leader in solving these problems, and to a large degree they are now under control.

Secondly, research is needed to lay the ground work for the future adoption by the Ministry of new materials and processes.

Both functions respond to Ministry policies.

It is suggested that the Ministry should consider the following policy options:

A. Improve and extend technology transfer within the Ministry, and between the Ministry and Industry.

B. Complete certain materials research and development programmes already started.

C. Establish and, if necessary, improve the service life of cover concrete.

D. Develop new generation materials for provincial highway applications.

E. Improve the aesthetics of structural concrete.

Tables 1 to 5 give details of the key components of these policy options. The programmes which would be required to implement these policies are described, as are the implications. Further, these programmes have been integrated into an overall programme which attempts:

1. To place them in an order of priority, having regard to their relative importance and the restrictions year by year of available budgets.

2. Insofar as is possible, to phase them to take maximum benefit of the results of other research, particularly the SHRP programme.

3. To integrate each R&D project into the overall technology transfer objectives, particularly the ongoing development of performance specifications.

Some miscellaneous projects are listed in Table 6. The programmes on salt scaling test procedures and curing of concretes containing high percentages of SCM's would not become high priority unless programmes S4 and S6 show higher quality cover concrete to be required.

TABLE 1: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

A. Improve And Extend Technology Transfer

Programmes	Projects	Implications
TT1 Ongoing monitoring and synthesis of R & D worldwide.	.1 Review existing staff involvement in national and international committees, professional associations, seminars and conferences.	• Need to assure adequate monitoring of state-of-the-art technology. • Additional staff costs for attendance at committee and technical meetings.
	.2 Review information network and modify where necessary to keep in touch with R & D worldwide.	• Additional staff costs.
	.3 Establish information transfer from staff to central data bank.	• Additional staff costs.
	.4 Make annual synthesis of R & D projects relevant to MTO.	• Additional staff costs.
	.5 Coordinate with TT2b.	• Insignificant additional staff costs, if any.
TT2 Increase liaison with industry.		
a) Establish committee with roadbuilding industry to optimise pavement quality.	.1 Review existing criteria for determining quality of PCC pavements.	• Insignificant additional staff costs, if any.
	.2 Establish initial mutually acceptable performance criteria for PCC pavements.	

TABLE 1: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

A. Improve And Extend Technology Transfer

Programmes	Projects		Implications
	.3	Establish ultimate target performance criteria for PCC pavements.	• MTO commitment to an ongoing kilometrage of PCC pavement. • Needs mutually cooperative approach. • Industry must accept the need to deliver in-place quality and the QC implications of this. • Requires review of achieved quality in other jurisdictions. • The Province needs optimum quality as soon as practical.
	.4	Establish tentative timetable to achieve ultimate target performance criteria.	• Need to relate achievement to targets.
	.5	Continue review of industry performance on an annual basis.	• Minor costs for travel, accommodation and, possibly, honoraria.
b) Establish committee on R & D.	.1	Annual meeting to review status of MTO R & D and recommend changes.	
c) MTO Structures Durability Committee meetings with industry.	.1	Meetings to be held in advance of the adoption of any new concept incorporated into performance specifications.	• Insignificant additional staff costs, if any. • Needs mutually cooperative approach.
	.2	Meetings to be held to review contract experience with previously implemented innovations.	• Insignificant additional staff costs, if any.

TABLE 1: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

A. Improve And Extend Technology Transfer

Programme		Projects	Implications
TT3 Improve Performance Level of QA Staff.			
.a) Increased training of MTO QA staff.	.1	Extend this already major activity to ensure QA staff understand the technology incorporated in new specification clauses.	• Significant additional costs. • Should include classroom, laboratory and in particular real life practice on sites.
.b) Establish performance criteria and budgets for QA by consultants.	.1	Write document establishing the types and frequencies of all tests required to achieve the desired level of QA.	• QA programme will change with each addition to the peformance specification.
	.2	Write specification for the qualification requirements and employment criteria of all levels of consultant staff required in QA procedures.	• Consultants will need to dedicate appropriate staff to a project. • MTO will have to show an ongoing availability of projects.
	.3	On a major project carry out field trials of the procedures and frequencies of tests and evaluate the results to confirm appropriate levels of QA.	
	.4	Based on the results of the trial draft a consultants' agreement with detailed requirements for staffing levels and competence.	
	.5	Determine appropriate budgets for these services.	• Substantially increased direct cost is probable.

TABLE 1: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

A. Improve And Extend Technology Transfer

Programmes	Projects		Implications
TT4 Continue move to performance specifications for concrete.	.1	Review results of R & D projects as they are reported.	• Ongoing committee activity.
	.2	Where necessary or desirable meet with the appropriate industry liaison committee.	• Dialogue will be desirable before implementing some changes to specifications. • There could be practical or financial implications to some proposed changes that industry should know in advance of implementation.
	.3	Incorporate results of each successful project into performance specification clauses.	• Ongoing committee activity.

TABLE 2: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

B. Complete R & D Programmes Already Started

Programmes		Projects	Implications
S1 Develop second generation grouts.	.1	Develop model high efficiency shear mixer.	• Fundamental to the production of optimum grout. • Industry will need to modify or change the mixers in use.
	.2	Develop pumpability test procedure to evaluate suitability of trial grouts.	• Test with relationship to field practice needed to evaluate characteristics over real use time.
	.3	Identify cement-admixture compatibility factors for impermeability and pumpability.	• Desirable unless one standard pre-mix formulation to be used.
	.4	Laboratory determination of optimum grout mix for strength, impermeability and pumpability.	• Improved corrosion protection of post-tensioned strands.
	.5	Laboratory mock-up trials of filling of typical duct configurations using optimum mix.	• Will simplify site grouting.
	.6	Full scale field trial of optimum mix.	• Low cost proving before moving to field trials.

TABLE 2: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

B. Complete R & D Programmes Already Started

Programmes		Projects	Implications
S2 Optimise the use of Shotcrete.	.1	Laboratory trial programme based on Appendix 5.	• Test programme design must cover all parameters relevant to MTO Bridge repair needs.
	.2	Study of small and automated or semi-automated plant to be specified for future use.	• Initial possible increase in shotcrete costs but far better probability of long term durability of repairs.
	.3	Field trials based on Appendix 5.	• Demonstration project required to prove new approach.
S3 Establish criteria for cover compliance.	.1	Establish the best cover-meter(s) for use on MTO projects including any limitations in use, and determine acceptance criteria for cover and cover measurement procedures.	• Even if some components cannot be assessed, performance requirements for cover are needed to improve compliance.

TABLE 3: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

C. Establish And If Necessary Improve The Service Life Of Cover Concrete

Programmes		Projects	Implications
S4 Establish the potential service life of cover concrete produced now.	.1	Laboratory determination of the characteristics of model concretes produced to OPSS 1350 requirements: .1 Physical properties, particularly permeability and absorption characteristics. .2 Effect of curing (temperature and moisture) on physical properties including microstructure. .3 Relationship of strength to quality (impermeability and sound microstructure) .4 Field survey of quality of cover concrete in structures built to current OPSS 1350 requirements. .1 Physical properties including permeability and absorption characteristics. .2 Microstructure including AVS. .3 In-place strength.	• Baseline criteria are needed for Ontario concretes as a basis for field evaluation of in-situ concrete for compliance with performance specifications. • Test procedures and acceptance criteria are needed to implement performance specifications. • Assumes successful completion of S6.1 and S6.2. • Need to know the quality being produced now. • Need to establish field test protocol for implementation of performance specifications.

TABLE 3: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

C. Establish And If Neccessary Improve The Service Life Of Cover Concrete

PROGRAMMES		PROJECTS	IMPLICATIONS
S5 If warranted by the results of S5 Projects improve the service life of cover concrete.	.1	Review of S4 and S6 project data and service life evaluation of OPSS 1350 concrete.	• Need must be established.
S6 Evaluate and select appropriate test methods for QA.	.1	Laboratory evaluation of permeability and absorption devices (ISAT, Modified ISAT, FIGG, CLAM, etc.)	• SHRP C204 experience can benefit this project. • Procedures needed for evaluation of cover concrete.
	.2	Field evaluation of permeability and absorption devices.	
	.3	Field evaluation of procedures for the determination of the determination of the AVS of fresh concrete.	• Procedure in service in Denmark. • SHRP C204, and SHRP IDEA • 007 and 011 contracts have procedures evaluated for field trials. • Successful implementation would enable MTO to specify AVS of concrete in-situ.
	.4	Field evaluation of in-situ methods of strength tests.	• SHRP 204 selected procedures are ready for field trials.

TABLE 3: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

C. Establish And If Neccessary Improve The Service Life Of Cover Concrete

PROGRAMMES	PROJECTS	IMPLICATIONS
		• May form part of a test protocol for acceptance of concrete structures built to performance specifications.
	.5 Laboratory evaluations of Advanced Maturity Systems (AMS).	
	.1 Determine maturity characteristics and heat signatures of model mixes meeting OPSS 1350 requirements.	• Needed for monitoring in-situ strength and curing.
	.2 Investigate use of AMS to predict cracking characteristics of large concrete placements on bridge decks.	• Could reduce or minimize cracking problems. • Could be a planning tool for advance determination of temperature controls as part of contractor planning. • Will provide criteria for protocols for curing and crack control in performance specifications.
	.6 Field evaluation of AMS for in-situ strength, curing and crack control.	• Needs careful planning for trial on one or more major bridge deck placements.

TABLE 4: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

D. Develop New Generation Materials For Provincial Highway Applications

Programmes		Projects	Implications
S7 Develop Self Compacting Concrete	.1	Laboratory programme to optimise cement-admixture combinations for cohesiveness and self-compaction.	• Ultimately anything that improves the cohesiveness and ease of compaction of concrete will improve the quality of concrete at any given level of QC.
	.2	Laboratory development and evaluation of model concrete including compaction trials in congested reinforcement with confirmation of the quality of cover concrete and compaction throughout the laboratory mock-ups.	
	.3	Field demonstration project.	• After successful demonstration industry will be expected to continue development and initiate use of this material. • MTO specifications will need modification.
S8 Develop High Early Strength Repair Concrete.	.1	Develop criteria for a durable, volume stable concrete.	• Assures freedom from the inclusion of unknown ingredients and from un-notified changes in formulation of proprietary materials. • Premixing assures QC and increases probability of good field performance.
	.2	Laboratory development using indigenous cements, SCM's admixtures and aggregates.	
	.3	Field trials of prototype premixed material.	

TABLE 4: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

D. Develop New Generation Materials For Provincial Highway Applications

Programmes		Projects	Implications
S9 Selection and Service Life of Repair Materials	.1	Monitor SHRP C103: "Concrete Bridge Protection And Rehabilitation, Physical And Chemical Methods" and C-SHRP project "Concrete Bridge Deck Rehabilitation Methods." Consider for adoption any materials or processes proven.	• Final products of both programmes due mid to late 1993. Interim results may be of interest.

TABLE 4: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

D. Develop New Generation Materials For Provincial Highway Applications

Programmes		Projects	Implications
P1 Develop High Early Strength Pavement Repair Material	.1	Continue laboratory development of existing mixes. Co-ordinate with S9. Design for very early high strength, volume stability, impermeability, and a stable air void system.	• Very fast-track repairs needed to minimize out-of-service time of pavements being repaired.
	.2	Proportion for highest possible workability and cohesiveness.	
	.3	Use AMS to develop maturity characteristics and heat signature. Design optimum curing regime for high early strength without loss of durability.	• Optimum mix proportioning will not of itself achieve high early strength and durability.
	.4	Field trials of optimum mix and curing regime with AMS monitoring.	• Specifications will need to address controlled curing as an integral part of the repair procedure.
P2 Develop High Performance Bridge Deck Overlays	.1	Laboratory programme to develop abrasion resistant highly impermeable, high resistivity overlays using SCM's and HRWR. .1 Optimize mix proportions for stated required properties.	• Could be more resistant to chloride ion ingress than overlays in use at present. • Abrasion resistance should be very high. • Skid resistance needs evaluation.

POLICY OPTION:

TABLE 4: PROGRAMMES PROJECTS AND IMPLICATIONS

D. Develop New Generation Materials For Provincial Highway Applications

Programmes		Projects		Implications
		.2	Determine heat signature and moisture related and thermal related dimensional change characteristics.	• Cost should be lower than some commonly used types of overlays. • Corrosion resistance should be very high.
		.3	Field trial of optimum mix with controlled curing cycle derived from P2.2 with AMS monitoring.	
P3	Develop High Performance Pavement Overlays	.1	Identify characteristics needed for durability and constructability.	• Provide option for rehabilitation of existing PCC pavements. • Alternative to asphaltic overlays. • Needs industry cooperation.
		.2	Laboratory trials to optimise model mix parameters, including AMS identification of heat signature and moisture related and thermal related dimensional change characteristics. Temperature effects of existing pavement to be considered.	
		.3	Field trial of optimum mix with controlled curing cycle derived from P3.2 with AMS monitoring.	
P4	Develop High Strength Pavement Mixes	.1	Laboratory test programme to optimise mix using specific high quality Ontario aggregates. Determine heat signature and optimum curing cycle using AMS.	• For pavement or localized pavement repairs. • High abrasion resistance. • Non-rutting alternative to asphaltic concrete at major intersections.

TABLE 4: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

D. Develop New Generation Materials For Provincial Highway Application

Programmes			Projects	Implications
		.2	Field trial including AMS monitoring of curing. Initial field trial limited to localized repairs.	
P5	Develop QC/QA Procedures.	.1	Complete development of FHWA Density monitoring device.	• Improved automation of measurement of compaction. • Early warning of vibrator malfunction.
		.2	Complete development of FHWA smoothness measuring device.	• Early assessment of plastic concrete allows correction during finishing operation.
P6	Establish Criteria For Re-Cycling Concrete From Pavements.	.1	Field trials of re-use in place using New York DOT "Rubbleising" procedure.	• Environmentally correct use of pavement concrete at end of service life.
		.2	Laboratory Development of criteria for the design of mixes using crushed concrete aggregates.	• Review of experience since 1920's.
		.3	Field trial using crushed concrete aggregates.	• Environmentally correct use of pavement concrete at end of service life.
P7	Investigate The Use of High Fly-Ash Content Mixes.	.1	Laboratory trials to optimize mixes and determine freeze-thaw durability, abrasion resistance, and heat signature using AMS.	• Low cost. • AAR control. • Utilization of waste material.
		.2	Field trial with controlled curing cycle monitored by AMS.	• Energy savings.

TABLE 5: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

E. Improve The Aesthetics Of Structural Concrete

Programmes		Projects	Implications
S10 Improve The Aesthetics Of Exposed Concrete.	.1	Design standard formwork closure details.	• Details previously left to contractor. • Increased costs for better closure details. • Decreased costs for repair of as formed surfaces. • Improved durability.
	.2	Review and standardize options for Architectural finishes.	• Increased costs for special finishes. • Intangible improvement in the visual environment.
	.3	Review the use of controlled permeability formwork (CPF) for Architectural finishes.	• Very uniform surfaces possible. • Improved durability aspects will have been investigated in projects S5 or S6.

TABLE 6: PROGRAMMES PROJECTS AND IMPLICATIONS

POLICY OPTION:

Miscellaneous Programmes:

Programmes		Projects	Implications
M1 Development of an improved salt scaling test for concrete particularly concretes containing large percentages of SCM's.	.1	Investigate effects of surface finish on test results.	• Will determine critical criteria for type of test specimen used. • Will confirm salt scaling resistance of concrete given optimum curing compared to inferior curing cycles.
	.2	Determine effects of different curing cycles on test results of concretes containing SCM's.	
M2 Development of optimum curing cycles for concrete containing large percentages of SCM's.	.1	Determine effects of different curing cycles on the properties of concretes containing SCM's. Use AMS to document heat signatures of mixes.	• Will form basis for curing specification for field concrete.
M3 Development of very high strength granite concrete curbs.	.1	Optimise very high strength mix and confirm durability characteristics.	• New product for Ontario pre-cast concrete industry.
M4 Development of No-Fines concrete as a drainage layer under PCC pavements.	.1	Building on extensive Ontario experience with No-Fines concrete optimise mix design procedures and practice.	• Durable • Effective drainage media. • Probably cheaper than open graded asphalt. • Drainage properties easier to control than open graded asphalt.

9./Recommended Policies

The concerns stated in the Needs Statement for this project have all been examined and have been found to be valid. It is concluded that the research plan developed in this report responds to important needs in the field of the Ministry's concrete work.

It is stated in section 8 that Ministry policies and Ministry research and development programmes are inter-active. It is germane then to examine some of the philosophical aspects of the policy options proposed for consideration.

The Research and Development Branch of the Ministry has long been active in all aspects of Technology Transfer. Staff have played a prominent role in National and International professional organizations and technical committees. There is also an ongoing level of dialogue with industry.

R&D activity in the near future has to take place within a framework of policy actions which respond to the problems stated in the RFP. The large volume of research on concrete materials presently being carried out worldwide mandates both an increase in the networking activities of R&D staff with other researchers and the establishment of a data base and synthesis of current research to facilitate the dissemination within the Ministry of developments that may have advantages to Ontario.

With regard to liaison with industry, the intent is not in any way to weaken the Ministry's right to specify. Rather, it is seen as a way to show industry the benefits, and enlist their cooperation in innovation. It will also allow lead time for industry to adapt to new specification requirements.

This is necessary, given the present level of QC common to contractors. The probability of successful compliance will then be increased. The role of an active dialogue on pavement quality is seen as an essential activity in achieving high quality with a riding ¸uality acceptable to the public. Given current economic trends, the ability to produce significant lengths of cost-effective pavement is seen as a potential benefit to the Province.

It is recognized that staff training and technical support will play a critical role in the ability to meet current and future challenges. Improvements in the knowledge and performance of QA staff are clearly needed. Additionally, as new technologies are introduced the level of both knowledge and skill in applying and interpreting more sophisticated evaluation procedures will increase. The appropriate performance criteria for QA staff, public and private, must be properly specified and executed. Significantly more QA staff are needed.

The consensus to move to performance specifications is overwhelming. The benefits in terms of innovation, better quality, and improved life-cycle costs are great. The difficulties in application are also great. Recognizing this, the plan envisages a step by step implementation of performance requirements. As each research programme is completed the relevant specification section is considered for modification to a performance requirement, and where appropriate, industry is consulted about the pending changes. It is also recognized that a completely performance oriented specification will, in all probability, never be achieved. This does not invalidate the benefits of taking the development of performance specifications as far as is possible and practicable.

All the programmes and projects in Policy Option A are recommended for adoption.

While priorities are discussed later, it seems good housekeeping to complete research programmes that have already been started but require further development to enable the benefits to be implemented on contracts.

No major effort is required to complete control of the alkali-aggregate problem. Further examination of the potentially greater use of low-alkali cement will almost surely allow the finalization of a comprehensive strategy.

The protection from corrosion of post-tensioning strands is of prime importance. Some valuable work has been funded by the R&D Branch, but further development of both plant and materials is necessary. The goal is a non-bleeding, non-shrinking grout of high resistivity and impermeability that can be readily pumped into long ducts without segregation.

The performance of shotcrete in Ontario has been below the standards of durability required by the Ministry. A successful first application of silica fume shotcrete was made this year on a bridge repair contract. Some of the potential benefits were obvious. In view of the importance of this material, it is considered that additional development should take place to optimise plant and mixes.

While there may still be some limitations in the performance of covermeters, models are available that are accurate on most components. The Ministry has introduced cover requirements that should produce a long service life if met. There are already QA procedures for checking this and evaluating compliance. After a small programme to determine the most reliable meter, performance requirements could be introduced into specifications.

The programmes and projects in Option B should be carried out to complete work already started, so that the benefits can be gained in the near future.

The most important and critical concrete in a structure is the cover concrete between the steel and the exterior surface of the structure. If a long service life is to be achieved it is necessary that this cover concrete be durable. Durability will result if the concrete is strong enough, contains a satisfactory air void system, has received adequate and correct thermal and moisture curing, and has a dense pore structure free of significant micro and macro defects. OPSS 1350 specifies high quality concrete that is typical of good modern practice. It is not known what is the quality of cover concrete produced now to this specification. The measurement of this quality will require the use of one or more test procedures, and determining the most suitable will require an evaluation programme. The characteristics of typical OPSS 1350 mixes will also need determination in the laboratory after a range of curing regimes to establish the criteria for the evaluation of concrete in the field. If the evaluation of field testing shows concrete produced now to the requirements of OPSS 1350 to be durable and with a predictably satisfactory service life, then no changes to practice will be needed. If the predicted service life is seen to be inadequate then a further, major research programme will be needed, which cannot be designed now.

In view of the importance of the quality of cover concrete the programmes and projects in Option C should be given high priority.

Option D includes all projects which bring new materials into use or, in some cases, improve present practice. The development of a durable volume stable high early strength concrete for pavement and structure repairs is a high priority throughout the highway industry. A system which uses materials of known properties and includes a specified and controlled heat and moisture curing regime will give the most consistent and reliable performance. It would also eliminate the uncertainities in the performance of proprietary materials and the unanticipated effects of changes in ingredients not known to the user.

There are potential benefits in the development of high performance concretes for bridge deck overlays, pavement overlays and finally, high strength concrete pavements. On bridge decks greater corrosion protection can be provided, and in all applications high resistance to abrasion and rutting can be achieved. Improvements in life cycle costs are possible with some of these applications. The three projects recommended build logically in sequence each one on the previous one. Because of the large volume of research data and experience in high performance and high strength concretes it is considered that the probability of success in these projects is high. The main effort will be in optimising the use of local materials within already established parameters.

The recycling of old pavements and the use of waste materials should form part of an overall programme of waste management, recycling and energy saving. The use of high fly ash mixes

in pavements has already been tried in Wisconsin. It is understood that a significant funding contribution to trials could be forthcoming from CANMET. A Provincial/Federal cooperative project could thus be carried out with insignificant use of MTO R&D funds.

Two QC/QA techniques that could help improve pavement quality have been developed to an advanced stage by FHWA, and some further development could be a low cost, high benefit project.

Despite significant research and development efforts in the last decade, our ability to design and execute durable repairs of predictably long service life is for most structural components imperfect. It seems fiscally prudent then to carry out the specific projects recommended in this plan and to monitor the major SHRP, C-SHRP and other research programmes on repair methods.

In the long run, anything that can be done to make the installation of concrete easier will lead to better quality. In due course a significant effort should be made in this area.

It is recommended that the projects comprising Option D be adopted with the S8 and P1 and P2 to P4 projects having a high priority.

In the long run societies are judged by their attitudes to the intangible qualities of life. Ancient Greece is seen to be a great civilization because of its devotion to its arts. What is proposed in Option E is a modest programme that will not only have the benefits of improved durability but will improve the visual quality of the environment. While it is difficult to show economic benefit it is to be sincerely hoped that Option E will be implemented.

10./Recommended Research Plan

In preparing the recommended plan consideration was given to the following factors which are relevant to its implementation.

- The interaction between the results of research projects and technology transfer.
- The research activity taking place in Canada and elsewhere so that unnecessary duplication is avoided.
- The likely timing of results of the research projects of other agencies that can beneficially feed into MTO needs.

In trying to determine priorities a number of factors have been considered. A distinction is made between chronological priority and priority due to the order of importance of a project.

- Since a number of important research projects already started require further funding these are given chronological priority in the interests of good housekeeping.
- In some cases projects considered to be high priority, such as those in Policy Option C, are delayed to optimise the input that can be gained from other programmes such as SHRP.
- Limitations in funding available precludes funding more than a proportion of the recommended projects at one time.

It is appreciated that any research plan must be flexible and that changes will be needed to take into account:

- The results of these and other research projects.
- Changes in operational needs.
- Changes in funding levels.

Such changes will flow in part from the annual review by the Research Review Committee.

A chronological research plan is shown on Tables 7 to 13, and within this plan priorities in terms of order of importance are considered to be as follows:

POLICY OPTION	PROGRAMME	PRIORITY
B	Programme S1 to S3 to complete R&D already started.	1
C	Programmes S4 to S6 to establish the potential service life of cover concrete produced now.	1
D	Programme S8 to develop high early strength repair concrete.	2
D	Programme P1 to develop high early strength pavement repair concrete.	2
D	Programmes P2 to P4 to develop new generation paving materials.	3
D	Programme P5 to complete development of new QC/QA procedures.	3
D	Programme S7 to develop self compacting concrete.	4
E	Programme S10 to improve the aesthetics of structural concrete.	4
D	Programmes P6 to re-cycle old pavements.	5
D	Programme P7 to investigate the use of high fly-ash mixes.	5

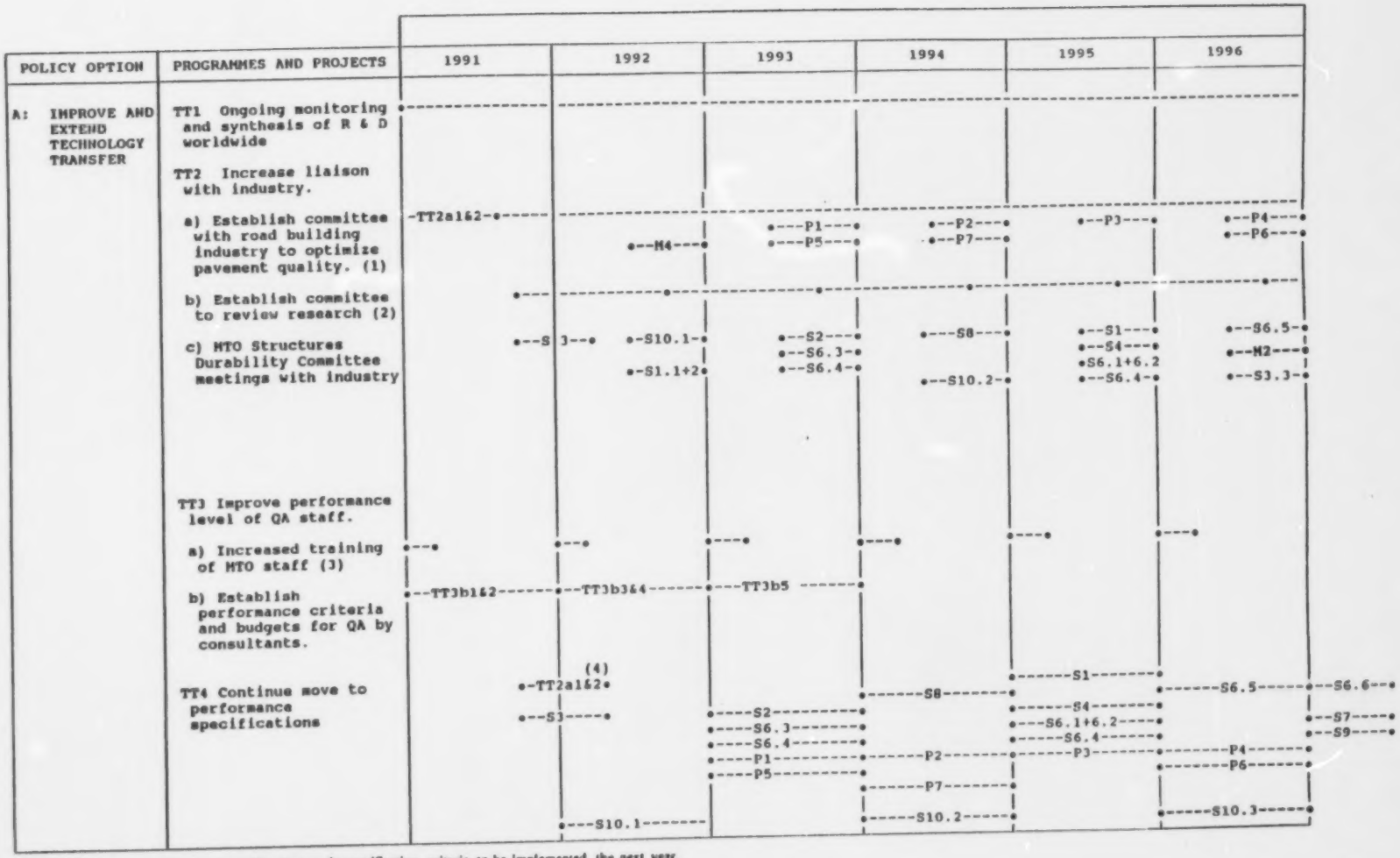
A summary of costs and benefits for the proposed programmes is given in Tables 14 to 18. Costs do not include the direct costs of the research programmes themselves whether conducted in-house or by consultants.

With regard to risk it is anticipated that all the programmes and projects recommended will result in progress in the form of improved knowledge, and most of them in improved practice.

The possible exceptions are programmes S4, S5 and S6, and S1.3. Developing a protocol for the early evaluation of the service life of cover concrete is a formidable challenge. While such a procedure is, in effect, being tried at Storebaelt it is felt that more research is needed to provide a basis for a performance specification.

The factors affecting the compatability of cement and admixtures have to date proven difficult to identify and control. Success in this project may not be forthcoming.

TABLE 7 TECHNOLOGY TRANSFER



1) Meets by mid year each year to enable changes in specification criteria to be implemented the next year.
2) Meets in Fall so that budget changes can be made for fulluwing year.
3) Training primarily in winter months.
4) Each R&D project on completion becomes a committee project, and the above table shows when the data from each research project with a designated prefix P or S becomes available to the technology transfer committees.

TABLE 8 COMPLETION OF PROJECTS ALREADY STARTED

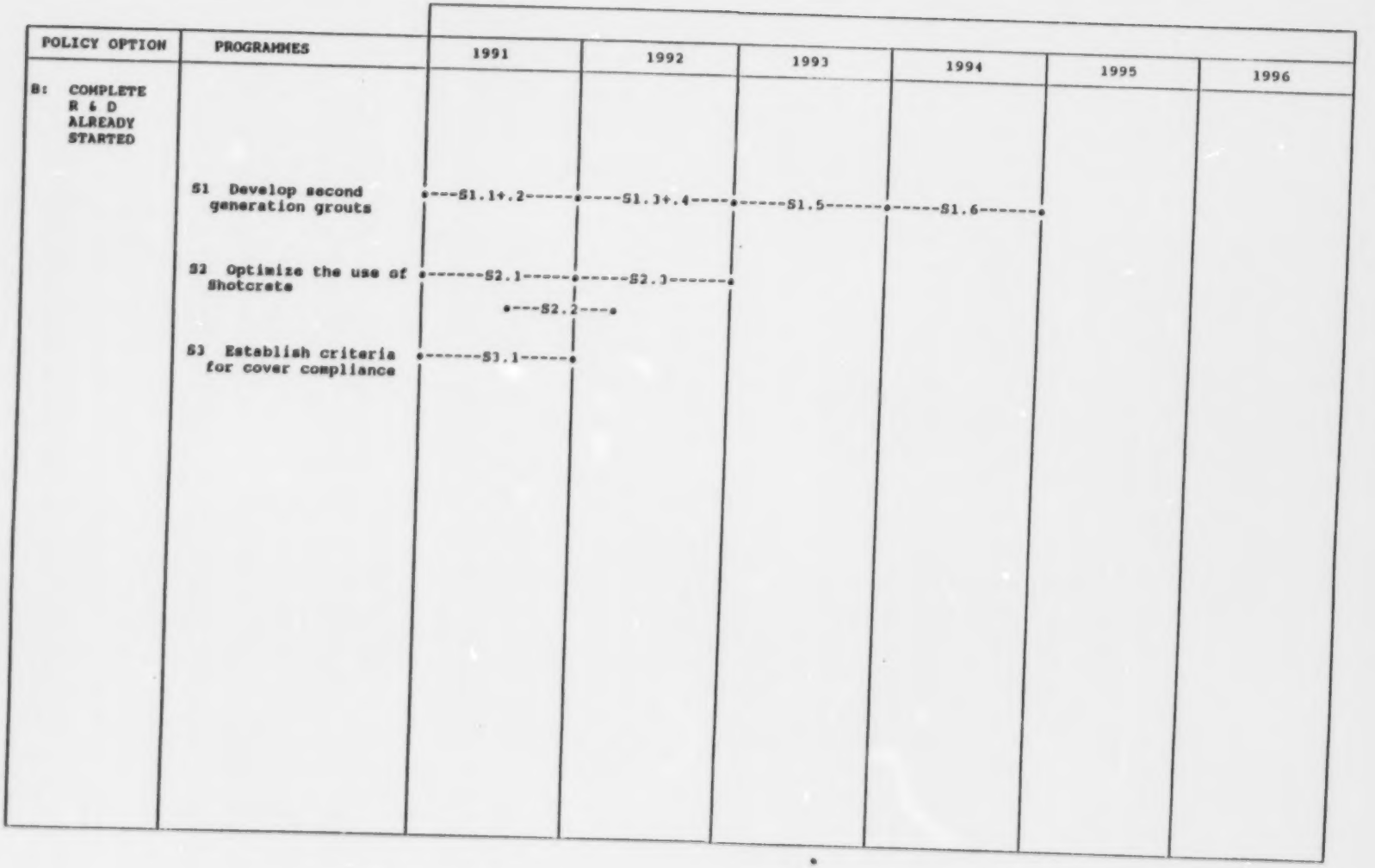


TABLE 9 ESTABLISH THE SERVICE LIFE OF COVER CONCRETE

POLICY OPTION	PROGRAMMES	1991	1992	1993	1994	1995	1996
C: ESTABLISH AND IF NECESSARY IMPROVE THE SERVICE LIFE OF COVER CONCRETE.	S4 Establish the potential service life of cover concrete produced now.			S4.1	S4.4		
				S4.2			
				S4.3			
	S5 If warranted by the results of S5 and S7 projects improve the service life of cover concrete.					S5.1	
	S6 Evaluate and select appropriate test methods for QA.		S6.1	S6.2			
			S6.3		S6.5.1	S6.5.2	S6.6
			S6.4				

TABLE 10 DEVELOP NEW GENERATION MATERIALS

POLICY OPTION	PROGRAMMES & PROJECTS	1991	1992	1993	1994	1995	1996
D: DEVELOP NEW GENERATION MATERIALS FOR PROVINCIAL HIGHWAY APPLICATIONS	S7 Develop self-compacting concrete.				S7.1	S7.2	S7.3
	S8 Develop high early strength repair concrete.	S8.1	S8.2	S8.3			
	S9 Monitor SHRP C103, and new C-SHRP Bridge Deck programme.			S9.1		S9.2	
	P1 Develop high early strength pavement repair concrete.	P1.1+1.2	P1.3+1.4				
	P2 Develop high performance bridge deck overlays.		P2.1+2.2	P2.3			
	P3 Develop high performance pavement overlays.			P3.1+3.2	P3.3		
	P4 Develop high strength pavement mixes.				P4.1	P4.2	
	P5 Develop QC/QA procedures.	P5.1	P5.2				
	P6 Establish criteria for re-cycling concrete from old pavements.					P6.1	
						P6.2	P6.3
	P7 Investigate the use of high fly-ash content mixes (if funded).		P7.1	P7.2			

TABLE 11 IMPROVE THE AESTHETICS OF STRUCTURAL CONCRETE

POLICY OPTION	PROGRAMMES & PROJECTS	1991	1992	1993	1994	1995	1996
E: IMPROVE THE AESTHETICS OF STRUCTURAL CONCRETE.	S10 Improve the aesthetics of structural concrete.						
	S10/1 Design standard formwork closure details. (1)	•----S10/1------•					
	S10/2 Review and standardize options for architectural finishes.			•-----S10/2-----•			
	S10/3 Review the use of controlled permeability formwork for architectural finishes. (2)					•-----S10/3-----•	

1) High priority because it improves durability as well as appearance.
2) Use of controlled permeability formwork for improved durability determined in project S5/x or S6/x.

TABLE 12 MISCELLANEOUS PROJECTS

POLICY OPTION	PROGRAMMES	1991	1992	1993	1994	1995	1996
M:							
MISCELLANEOUS PROJECTS	M1 Development of an improved salt scaling test for concrete particularly concretes containing large percentages of SCM's.						•------M1-------•
	M2 Development of optimum curing cycles for concrete containing large percentages of SCM's.					•------M2-------•	
	M3 Development of very high strength granite concrete curbs.						•------M3-------•
	M4 Development of no-fines concrete for drainage layer under PCC pavement.	•------M4-------•					

TABLE 13 OVERALL SUMMARY OF PROJECTS

POLICY OPTION	PROGRAMMES	1991	1992	1993	1994	1995	1996
B.	S1	S1.1+2.2	S1.3+2.4	S1.5	S1.6		
	S2	S2.1	S2.3				
		S2.2					
	S3	S3.1					
C.	S4			S4.1	S4.4		
				S4.2			
				S4.3			
	S5					S5.1	
	S6		S6.1	S6.2			
			S6.3		S6.5.1	S6.5.2	S6.6
			S6.4				
	S7				S7.1	S7.2	S7.3
	S8	S8.1	S8.2	S8.3			
	S9			S9.1		S9.3	
	P1	P1.1+1.2	P1.3+1.4				
	P2		P2.1+2.2	P2.3			
	P3			P3.1+3.2	P3.3		
	P4				P4.1	P4.2	
	P5	P5.1	P5.2				
	P6					P6.1	
						P6.2	P6.3
	P7		P7.1	P7.2			
D.	S10	S10.1		S10.2		S10.3	
M.	M1						M1
	M2					M2	
	M3						M3
	M4	M4					

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AAR	Alkali-aggregate reaction/reactivity.
AMS	Advanced maturity system in which a combination of test hardware and computer software is used to develop maturity data of concrete mixtures. Basic data on the maturity characteristics (fingerprint) can be used to predict strength at various ages and temperature gradients in structural components of differing dimensions. The system can also be used to monitor the temperature and maturity of structural components. The basis of this technology has been well explained by Idorn [56].
ASR	Alkali-silica reaction.
AVS	Air void system. Data that describes the amount of air, size and spacing factor of air bubbles in concrete or cement paste.
CPF	Controlled Permeability Formwork. Formwork in which the absorption characteristics of the layer next to the concrete has specific absorption characteristics. This is usually achieved by fixing a geotextile fabric to the form face. Air bubbles are absorbed and also water increasing the potential durability of the surface concrete.
EMO	Engineering Materials Office of the MTO
HPC	High Performance Concrete.
HRWR	High range water reducer or superplasticiser.
QC	Quality Control. This covers all operations by a contractor and his suppliers to ensure the quality of their product.
QA	Quality Assurance. This covers all operations by an owner or his representatives to confirm that the quality of the products purchased is in compliance with specification requirements.
SCC	Self compacting concrete. Concrete that will flow into formwork containing congested reinforcement and compact with very little compactive effort. Such concrete is highly resistant to segregation.
SCM	Supplementary Cementing Materials. Blast furnace slag, fly-ash and silica fume.

APPENDIX I

BENEFIT - COST ANALYSIS OF CONCRETE RESEARCH POLICY OPTIONS AND PROGRAMMES.

TABLE 14

POLICY OPTION A: Improve And Extend Technology Transfer

Programme TT1: Ongoing Monitoring And Synthesis Of R&D Worldwide

COSTS

- Increased staff activity at conferences and seminars and on technical committees.
- Some internal costs to operate data bank.

BENEFITS

- Improves ability to benefit early from research results beneficial to MTO.
- Optimises and reduces MTO research expenditures.

Programme TT2: Increase Liaison With Industry

COSTS

- Minor increased staff costs for increase in activity on these local committees.
- Some modest costs for consultant activity on research review committee.

BENEFITS

- Optimises and reduces MTO research expenditures.
- Ensures industry cooperation in implementing new specification requirements.
- Increases probability of successful implementation of new technology.

Programme TT3: Improve Performance Level Of QA Staff

COSTS

- Essential costs for improved performance of MTO and Consultants' QA staff.

BENEFITS

- Ability to implement and enforce performance specifications.

Programme TT4: Continue Move To Performance Specifications

COSTS

- Minor staff costs.

BENEFITS

- Maximises the beneficial adoption of innovation.
- Facilitates the improvement of service life performance of MTO structures and pavements

TABLE 15

POLICY OPTION B: Complete R & D Programmes Already Started

Programme S1: Develop Second Generation Grouts

COSTS

- Industry may be faced with significant, but not unmanageable costs to modify or replace grout mixers and pumps.
- Industry will absorb costs of initial set-up to produce pre-mixed grout.

BENEFITS

- Improved assurance that post-tensioning tendons will be protected from corrosion.
- Reduced possibility of freeze-thaw damage due to freezing of bleed water.
- Improved pumpability of grout will reduce industry grouting costs.

Programme S2: Optimise The Use Of Shotcrete

COSTS

- Industry costs to upgrade equipment will be significant but can be viewed as inevitable if industry is to become up-to-date technologically.

BENEFITS

- Cost of shotcrete should decrease.
- Improved durability of shotcrete repairs.
- Industry will benefit long term by increased efficiency and ability to offer better quality product.

TABLE 15

POLICY OPTION B: **Complete R & D Programmes Already Started**

Programme S3: **Establish Criteria For Cover Compliance**

COSTS

- No costs to industry since specification already requires specific cover and contractor is paid to provide it.
- No costs to MTO since compliance is already measured as a routine QA procedure.

BENEFITS

- Specification requirements will be met in this critical area.

TABLE 16

POLICY OPTION C: Establish And If Necessary Improve The Service Life Of Cover Concrete

Programme S4: Establish The Potential Service Life Of Cover Concrete Produced Now

COSTS

- No costs outside R & D budget.

BENEFITS

- By comparing the quality of laboratory and and field contractors the current degree of compliance to OPSS 1350 can be determined.
- If necessary compliance can be improved by the introduction of new performance requirements.
- If the potential quality of cover concrete is adequate for the desired service life then more expensive cover concrete is not required.
- If the potential quality of cover concrete is inadequate for the desired service life then a higher quality concrete is necessary and its initially higher cost justified.

Programme S5: If Warranted By The Results Of S5 Projects Improve The Service Life Of Cover Concrete

COSTS

- No costs outside R & D budget at this stage for review of S4 data.

BENEFITS

- Review of S4 data will either confirm the adequacy of existing cover concrete, or show the need for improvement.

Programme S6: Evaluate And Select Appropriate Test Methods For QA

COSTS

- Purchase costs for new QA test equipment.

BENEFITS

- Will enable performance specifications for concrete quality to be implemented.
- Early assurance of in-place AVS quality is possible.

TABLE 17

POLICY OPTION D: Develop New Generation Materials For Provincial Highway Applications

Programme S7: Develop Self-Compacting Concrete

COSTS

- Costs of concrete must be expected to be higher than that for conventional concrete.

BENEFITS

- Lower placing costs.
- Better appearance.
- Improved durability.
- Reduced repair costs.

Programme S8: Develop High Early Strength Repair Material

COSTS

- Cost of concrete must be expected to be higher than that of conventional concrete but should be cheaper than proprietary alternatives.

BENEFITS

- Ontario product.
- Known reliability of ingredients and performance.
- Guarantee for reduced downtime of repaired structures.
- Known durability properties.

Programme S9: Monitor SHRP C103 and C-SHRP Bridge Deck Programmes

COSTS

- Minor staff costs.
- Minor travel costs.

BENEFITS

- Optimises MTO activity and expenditure on bridge repairs.

Programme P1: Develop High Early Strength Pavement Repair Concrete

COSTS

- Cost of concrete must be expected to be higher than that of conventional concrete but should be cheaper than proprietary alternatives.

BENEFITS

- Ontario product.
- Known reliability of ingredients and performance.
- Guarantee for reduced downtime of repaired pavements.
- Known durability properties.

TABLE 17

POLICY OPTION D: Develop New Generation Materials For Provincial Highway Applications

Programme P2: Develop High Performance Bridge Deck Overlays

COSTS	BENEFITS
• None.	• Reduced material costs and absence of different plant requirements should lower costs. • Improved impermeability to chloride ions. • Improved corrosion protection to bridge decks. • High abrasion resistance.

Programme P3: Develop High Performance Pavement Overlays

COSTS	BENEFITS
• Initial cost of concrete overlay may be higher than asphaltic concrete.	• Alternative to asphaltic concrete. • Longer life than asphaltic concrete. • Very high resistance to rutting and abrasion. • Low life-cycle cost.

Programme P4: Develop High Strength Pavement Mixes

COSTS	BENEFITS
• Initial cost of concrete pavement will be higher than normal strength concrete pavements.	• Very high resistance to rutting and abrasion. • Low life-cycle costs for construction of major highway intersections.

TABLE 17

POLICY OPTION D: Develop New Generation Materials For Provincial Highway Applications

Programme P5: Develop QC/QA Procedures

COSTS	BENEFITS
• Increased cost to contractor to purchase and implement the use of the equipment.	• Early warning of potential problems with pavement quality. • Low cost of remedial action compared to later repair or rejection.

Programme P6: Establish Criteria For Re-Cycling Concrete From Old Pavements

COSTS	BENEFITS
• Rubbleising or crushing old pavement concrete.	• Re-use in place of existing pavement as base for new pavement. • Re-use of old concrete to make new concrete pavement. • Beneficially environmentally. • Energy saving.

Programme P7: Investigate The Use Of High Fly-Ash Content Mixes

COSTS	BENEFITS
• Minor costs for handling an extra cementitious material.	• Lower cost. • Use of waste material. • Energy saving.

TABLE 17

POLICY OPTION E: Improve The Aesthetics Of Structural Concrete

COSTS	BENEFITS
• Additional but not significant forming costs.	• Improved aesthetics. • Improved durability. • Reduced repair costs.

TABLE 18

POLICY OPTION: **Miscellaneous Projects**

Programme M1: **Improved Salt Scaling Test**

COSTS	BENEFITS
• None	• Better prediction of potential durability • May allow beneficial use of greater amounts of SCM's in future.

Programme M2: **Optimum Curing Cycles For SCM's**

COSTS	BENEFITS
• None	• May allow beneficial use of greater amounts of SCM's in future.

Programme M3: **High Strength Concrete Curbs**

COSTS	BENEFITS
• None	• Lower life-cycle cost for curbs. • New product for Ontario industry.

Programme M4: **No-Fines Drainage Concrete**

COSTS	BENEFITS
• None	• Better drainage. • Lower costs.

APPENDIX II

LIST OF CONTACTS MADE DURING STUDY

Ministry of Transportation, Ontario

Research and Development Branch

Peter Smith, Director
Dr. David G. Manning
Dr. Alan K.C. Ip

Engineering Materials Office

Roger P. Northwood, Manager
Hannah Schell
Chris Rogers
Ken Carter

Regional Staff

Fred Bennitz
Bob Armstrong
Rick Larman
V. Posius
M.I.G. Keizars
A. Gaffar

Structural Office

Roger A. Dorton, Manager

U.S. Federal Highway Administration

Thomas J. Pasko - Director of Engineering and Highway Operations Research and Development
Dr. Terry M. Mitchell

New York State Department of Transportation

Richard H. Obuchowski - Materials Bureau
William M. McCarty
Paul E. Ducharme

Department of Transportation, Commonwealth of Pennsylvania

Charles A. Kline - Chief Materials & Testing Division
Donald C. Casner - Chief Engineering Technology Division
David R. Reidenour - Bureau of Materials
Dr. Umakant Dash - Chief Evaluation & New Products Section

Academia

Dr. Brian B. Hope - Queens University
Dr. R.D. Hooton - University of Toronto

Canadian Portland Cement Association

Eric Fines - National Manager
Peter Weisenen - Regional Manager, Ontario

Ready-Mixed Concrete Association of Ontario

Alan Baxter - General Manager
John D. Hull - Director of Marketing

Ontario Hydro
Pranab K. Muhkerjee

Trow Inc.
John Ryell - Vice President

Harris Rebar
John Prosser - Vice President

Matex Consultants
Dr. R.T. Hemmings - Principal

Hardy BBT
Dr. D.R. Morgan - Chief Materials Engineer

Selmer Furuholen, Oslo (Road Contractor)
Steinar Helland

Chemical Admixtures

Trent Ogilvie - Sternson
Phil Zacarias - Conchem
Brian Salazar - Euclid
Andy Mitchell - Sika
Claude Bedard - Mulco
Don Grey - Mulco
Don Lamb - Master Builders
Jim Parsons - W.R. Grace

Custom Concrete
Dan Notari - Operations Manager

SFRC Services Inc.
L.D. Wallace - President

C.I.M.S.
Farro Radjy

Taywood Engineering (U.K.)

Dr. P. Bamforth
Dr. W. Price

Ministry of Transport (U.K.)

D.B. Storrar

AEC Consulting Engineers (Denmark)

E. Poulsen, Principal
T.S. Hansen, Petrographer
J.M. Frederiksen, Engineer

Technical University of Denmark

Professor M.P. Nielsen

Du Pont De Nemours (Germany)

C. Marx, Dipl-Ing.

CANMET

M. Malhotra.

B.H. Levelton & Associates Ltd.

P.T. Seabrook.

APPENDIX III

TECHNICAL MEETINGS ATTENDED DURING STUDY

May 2 - 3 International Workshop on Alkali-Aggregate Reactions in Concrete, Halifax.

May 16 - 18 NIST Workshop on High Performance Concrete, Washington

May 21 - 23 2nd International Symposium on Utilization of High Strength Concrete, Berkeley

June 4 - 5 CUIAC Workshop on Advanced Chemically Bonded Ceramics (Cements)

Sept. 11 - 13 The Protection of Concrete, Dundee University

Sept. 27 - 28 SHRP 204 Review Meeting, Cornell University

October 10th Concrete in Economical Buildings, Toronto

October 11-12 Network of Centres of Excellence; High Performance Concrete, University of Sherbrooke.

These meetings were attending during the course of the project and the opportunity was taken to discuss with many delegates from around the world the technical issues addressed in this project.

APPENDIX IV

DBT Air Void Analyser

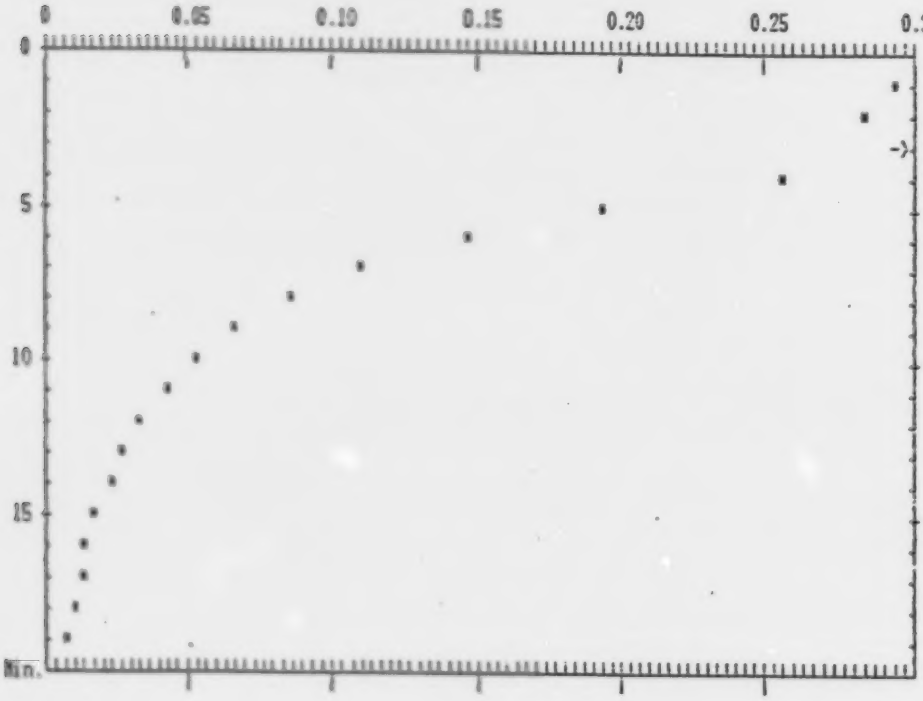
Typical Test Printout

DBT - Luftporemåler Serie 2/1
European Storebaelt Group

Dato	:	03/07/90			
Prøvetager	:	pv			
Rekvirent	:	esg			
Udtagningssted:		nyborg			
Sag nr.	:	9990			
Prøve nr.	:	3/1			
Mørtel <6 mm %:		51.8 %	Pasta %	:	26.4 %
Forv. luft % :		6.0 %	Prøvevol. cm3:		20.0 cm3

Analyse:

.Start	+5 sek.	Temp.
0.00 g	0.02 g	22.3 C



DIF.	-15	Min.	+15	Temp.
29.3	0.22	0.28	0.38	23.0
28.3	0.49	0.56	0.68	23.1
-> 30.3	0.79	0.87	0.98	23.1
25.7	1.07	1.13	1.21	23.1
19.3	1.28	1.32	1.39	23.1
14.7	1.44	1.47	1.52	23.2
11.0	1.56	1.58	1.62	23.2
8.7	1.65	1.67	1.70	23.2
6.7	1.72	1.74	1.76	23.2
5.3	1.78	1.79	1.81	23.1
4.3	1.82	1.84	1.85	23.1
3.3	1.86	1.87	1.88	23.2
2.7	1.89	1.89	1.91	23.1
2.3	1.91	1.92	1.93	23.1
1.7	1.93	1.94	1.94	23.1
1.3	1.95	1.95	1.95	23.1
1.3	1.96	1.96	1.97	23.1
1.0	1.97	1.97	1.98	23.0
0.7	1.98	1.98	1.98	23.0

Resultat:

Porediameter :	Total	<3 mm.	<0.5 mm.
Luft% beton :	5.7 %	5.7 %	5.5 %
Luft% pasta :		21.5 %	20.6 %
Luft% kitmasse :		17.7 %	16.9 %
Specifik overflade		38.1 mm.-1	
Afstandsfaktor		0.12 mm.	

Bemærkninger :

del note 002485 (6.8%)
base 63
after pumping
b mix

Sign._____

APPENDIX V

TABLE 1

Suggested Test Variables for Shotcrete Repair of Bridges Study

	ITEM	DESCRIPTION
A	Shotcrete Mixture (both wet and dry-mix shotcrete)	1) Plain shotcrete 2) Latex modified shotcrete 3) Silica Fume shotcrete
B	Surface preparation	1) None (other than washing) 2) Chipping 3) Chipping and sand-blasting 4) Chipping and high pressure water blasting.
C	Reinforcement and crack control	1) No reinforcement 2) Mesh reinforced shotcrete 3) Steel fibre reinforced shotcrete 4) Wet-mix, polypropylene fibre reinforced shotcrete (at say 3 and 5 kg/m^3 addition rate)
D	Anchorage	1) With anchors at say two different spacing patterns 2) With no anchors (mesh will obviously require some)
E	Curing	1) No curing 2) Continuous moist curing for 3 days 3) Spray applied curing compound
F	Thickness of Shotcrete Application	1) Single 100 mm thick layer 2) Flash coat, say 10 mm thick on concrete 3) Flash coat over 100 mm thick first shotcrete layer
G	Finishing	1) Natural as-shot finish 2) Screeded and floated.

TABLE 2

Suggested Test Variables

	DESCRIPTION	SPECIMENS/MIX
A	ON STANDARD SHOTCRETE TEST PANELS (450 x 450 x 100 mm)	
1)	Compressive Strength	2/75 mm diameter cores at 7 and 28 days
2)	Flexural strength and toughness index I_5, I_{10}, I_{20} to ASTM C 1018	3/75 x 75 x 350 mm prisms at 7 days (fibre mixes only)
3)	Boiled absorption and volume of permeable voids to ASTM C642	2/75 mm diameter cores at 28 days
4)	Parameters of the air void system to ASTM C457	1/100 mm diameter core
5)	De-icing chemical scaling resistance to ASTM C672 to 50 cycles	1/200 x 250mm prisms
6)	Freeze/thaw resistance to ASTM C666, Procedure A to 300 cycles	3/75 x 90 x 400 mm prisms
7)	Rapid chloride permeability to AASHTO T 277-83	2/94 mm diameter x 50mm
8)	Drying shrinkage to ASTM C341, start drying at age 7 days	2/75 x 75 x 285 mm prisms
B	IN-SITU SHOTCRETE TESTS	
1)	Delamination survey: by sounding	
2)	Cracking survey: crack pattern and width	
3)	In-situ bond strength: 75mm diameter pull-off cores 28 days	
4)	Test bond strength cores at age 28 days: for compressive strength	